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THE APPLICATION OF BIOCYBERNETIC TECHNIQUES TO ENHANCE PILOT PERFORMANCE DURING TACTICAL MISSIONS

1 OCTOBER 1979

MDC E2046

FINAL REPORT

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TABLE OF CONTENTS

LIST OF FIGURES		iv
LIST OF SYMBOLS AND ABBREVIATIONS		x
PREFACE		xvi
SECTION 1.0	ABSTRACT	1
SECTION 2.0	INTRODUCTION	4
SECTION 3.0	AN OVERVIEW OF MISSION TYPES AND PROJECTED TECHNOLOGY ADVANCES FOR TACTICAL AIRCRAFT	8
	3.1 Mission Types	12
	3.2 Technology Advances	20
	3.2.1 Weapons	20
	3.2.2 Avionics	25
	3.2.2.1 Sensors	25
	3.2.2.2 Electronic Displays	27
	3.2.2.3 Multifunction Control Unit	33
	3.2.2.4 Voice Actuated Controls	34
	3.2.2.5 Joint Tactical Information Distribution System	35
	3.2.2.6 Airborne Warning And Control System	36
	3.2.2.7 Global Positioning Satellite	36
SECTION 4.0	MISSION REQUIREMENTS	37
SECTION 5.0	INFORMATION NEEDS	59
SECTION 6.0	PILOT PERFORMANCE AND BIOCYBERNETIC APPLICATIONS	72
	6.1 Time Line Analysis of Pilot Tasks	72
	6.1.1 Launch	79

TABLE OF CONTENTS (Continued)

	6.1.2	Climb	81
	6.1.3	Rendezvous	83
	6.1.4	Ingress	85
	6.1.5	Medium Range Intercept	87
	6.1.6	Surface-To-Air Missile Avoidance	89
	6.1.7	Air Combat Maneuvering	91
	6.1.8	Air-To-Ground Strike	93
	6.1.9	Egress	95
	6.1.10	In-Flight Refuel	97
	6.1.11	Marshal	99
	6.1.12	Prelanding	101
	6.1.13	Landing	103
	6.2	Real-Time Analysis And Interpretation Of Biological Signals	105
	6.2.1	Brain Electrical Activity	109
	6.2.2	Peripheral Activity	120
	6.2.2.1	Psychophysiological Responses	121
	6.2.2.2	Ocular Activity	122
	6.3	Biocybernetic Applications	126
SECTION 7.0		CONCLUSIONS AND RECOMMENDATIONS	144
SECTION 8.0		REFERENCES	147

LIST OF PAGES

Title Page
ii through xvi
1 through 150

LIST OF FIGURES

FIGURE NUMBER	TITLE
3.1	Integrated Crew Station Concept For A 1990 Tactical Aircraft.
3.2	Descriptions Of The Instruments Depicted In Figure 3.1.
3.3	Pictorial Representation Of The Three TACAIR Missions.
3.4	General Mission Requirements For Pre-Flight, In-Flight, And Post-Flight Phases.
3.5	Mission Profile For Close Air Support.
3.6	Mission Profile For Air Interdiction.
3.7	Mission Profile For Counter Air.
3.8	Guidance Systems And Their Characteristics.
3.9	Types Of Air-To-Air Missiles.
3.10	Types of Air-To-Surface Ballistic Weapons.
3.11	Types of Air-To-Surface Missiles.
3.12	Anticipated Avionics Advances.
3.13	Sensor Characteristics.
3.14	Information Formats And Display Coding Schemes.
3.15	Comparison Of Display Technologies With Respect To Information Formats And Coding Schemes.
3.16	Evaluation Parameters And Corresponding Performances Of Selected Display Devices.
4.1	Pre-Flight Mission Requirements For Close Air Support, Air Interdiction, and Counter Air.
4.2	Pre-Flight Mission Requirements (Continued).
4.3	Pre-Flight Mission Requirements (Continued).

LIST OF FIGURES (Continued)

FIGURE NUMBER	TITLE
4.4	Pre-Flight Mission Requirements (Concluded).
4.5	In-Flight Mission Requirements For Close Air Support, Air Interdiction, and Counter Air.
4.6	In-Flight Mission Requirements (Continued).
4.7	In-Flight Mission Requirements (Continued).
4.8	In-Flight Mission Requirements (Continued).
4.9	In-Flight Mission Requirements (Continued).
4.10	In-Flight Mission Requirements (Continued).
4.11	In-Flight Mission Requirements (Continued).
4.12	In-Flight Mission Requirements (Continued).
4.13	In-Flight Mission Requirements (Continued).
4.14	In-Flight Mission Requirements (Continued).
4.15	In-Flight Mission Requirements (Continued).
4.16	In-Flight Mission Requirements (Continued).
4.17	In-Flight Mission Requirements (Continued).
4.18	In-Flight Mission Requirements (Continued).
4.19	In-Flight Mission Requirements (Concluded).
4.20	Post-Flight Mission Requirements For Close Air Support, Air Interdiction, and Counter Air.
4.21	Post-Flight Mission Requirements (Concluded).
5.1	Information Requirements For Close Air Support.
5.2	Information Requirements For Close Air Support (Continued).

LIST OF FIGURES (Continued)

FIGURE NUMBER	TITLE
5.3	Information Requirements For Close Air Support (Continued).
5.4	Information Requirements For Close Air Support (Concluded).
5.5	Information Requirements For Air Interdiction.
5.6	Information Requirements For Air Interdiction (Continued).
5.7	Information Requirements For Air Interdiction (Continued).
5.8	Information Requirements For Air Interdiction (Concluded).
5.9	Information Requirements For Counter Air.
5.10	Information Requirements For Counter Air (Continued).
5.11	Information Requirements For Counter Air (Continued).
5.12	Information Requirements For Counter Air (Concluded).
6.1	Segments Of A Carrier Launched Escort Mission.
6.2	Representative Profile For A Carrier Launched Escort Mission.
6.3	Schematic Configuration Of F/A 18 Crew Station.
6.4	Anticipated Task Loadings During Segments Of A Carrier Launched Escort Mission.
6.5	Dynamic Task Flows For Launch.
6.6	Dynamic Task Flows For Climb.

LIST OF FIGURES (Continued)

FIGURE NUMBER	TITLE
6.7	Dynamic Task Flows For Rendezvous.
6.8	Dynamic Task Flows For Ingress.
6.9	Dynamic Task Flows For Medium Range Intercept.
6.10	Dynamic Task Flows For SAM Avoidance.
6.11	Dynamic Task Flows For Air Combat Maneuvering.
6.12	Dynamic Task Flows For Air-To-Ground Strike.
6.13	Dynamic Task Flows For Egress.
6.14	Dynamic Task Flows For In-Flight Refueling.
6.15	Dynamic Task Flows For Marshal.
6.16	Dynamic Task Flows For Prelanding.
6.17	Dynamic Task Flows For Landing.
6.18	Biological Signals Considered As Inputs For Biocybernetic Applications.
6.19	Electroencephalogram Of A Normal Human Adult.
6.20	Vertex Event-Related Potential Elicited By A Matching Letter Presentation During An Item Recognition Task.
6.21	Lateral And Superior Views Of International Electrode Placement System.
6.22	Typical CNV Waveform Recorded From Vertex Electrode Placement.
6.23	(A) The Displayed Scene And (B) The Eye-Scan Pattern And Vertex EEG Of One Subject Before And After Detection Of Vehicle.

LIST OF FIGURES (Continued)

FIGURE NUMBER	TITLE
6.24	Examples Of Vertex Readiness Potentials Associated With Finger Presses During A Reaction Time Task and During Voluntary Movements.
6.25	Relationship Between Particular Biological Signals And Either The Determination Of Pilot Status Or Control Functions.
6.26	Biocybernetic Applications As A Function Of Pilot Tasks During Launch.
6.27	Biocybernetic Applications As A Function Of Pilot Tasks During Climb.
6.28	Biocybernetic Applications As A Function Of Pilot Tasks During Rendezvous.
6.29	Biocybernetic Applications As A Function Of Pilot Tasks During Ingress.
6.30	Biocybernetic Applications As A Function Of Pilot Tasks During MRI.
6.31	Biocybernetic Applications As A Function Of Pilot Tasks During SAM Avoidance.
6.32	Biocybernetic Applications As A Function Of Pilot Tasks During ACM.
6.33	Biocybernetic Applications As A Function Of Pilot Tasks During A/G Strike.
6.34	Biocybernetic Applications As A Function Of Pilot Tasks During Egress.

LIST OF FIGURES (Continued)

FIGURE NUMBER	TITLE
6.35	Biocybernetic Applications As A Function Of Pilot Tasks During In-Flight Refueling.
6.36	Biocybernetic Applications As A Function Of Pilot Tasks During Marshal.
6.37	Biocybernetic Applications As A Function Of Pilot Tasks During Prelanding.
6.38	Biocybernetic Applications As A Function Of Pilot Tasks During Landing.

LIST OF SYMBOLS AND ABBREVIATIONS

AAA	Anti-Aircraft Artillery
A/A	Air-to-Air
AAR	Air-to-Air Refueling
A/C	Aircraft
ACM	Air Combat Maneuvering
ADC	Air Data Computer
ADF	Automatic Direction Finder
ADI	Attitude Direction Indicator
AFCS	Automatic Flight Control System
A/G	Air-to-Ground
AGL	Altitude above Ground Level
AGM	Air-to-Ground Missile
AGR	Air-to-Ground Ranging
AI	Air Interdiction
AIM	Air Intercept Missile
ALCM	Air Launched Cruise Missile
AOA	Angle-of-Attack
APC	Armored Personnel Carrier
AWACS	Airborne Warning And Control System
AZ	Azimuth
BCIU	Bus Control Interface Unit
BDM	Bomber Defense Missile
Bingo	Level of fuel necessary to return to airfield
BITE	Built In Test Equipment

LIST OF SYMBOLS AND ABBREVIATIONS (Cont'd)

BLU	Bomb Live Unit
C^3	Command,Control and Communication
CA	Counter Air
CAS	Close Air Support
CBU	Cluster Bomb Unit
C/D	Controls and Displays
CET	Central European Theatre
CNI	Communication, Navigation, Identification
CNV	Contingent Negative Variation
COM	Communication
CRT	Cathode Ray Tube
DAIS	Digital Avionics Information System
DARPA	Defense Advanced Research Projects Agency
DBS	Doppler Beam Sharpened
DME	Distance Measuring Equipment
DP	Detection Potential
ECG	Electrocardiogram
ECM	Electronic Countermeasure
EEG	Electroencephalogram
EL	Elevation
EL	Electroluminescence
EMD	Electromechanical Device
EMG	Electromyogram
EO	Electro-optical

LIST OF SYMBOLS AND ABBREVIATIONS (Cont'd)

EOG	Electro-oculogram
EPI	Elements Per Inch
ERP	Event-Related Potential
F/A	Fighter/Attack
FAC	Forward Air Controller
FEBA	Forward Edge of the Battle Area
FLIR	Forward Looking Infrared
FLR	Forward Looking Radar
FOV	Field-Of-View
ftL	Foot Lambert
g	Gravity
GBU	Guided Bomb Unit
GMTI	Ground Moving Target Indicator
GPS	Global Positioning Satellite
HACQ	Horizontal Acquisition
HMD	Helmet-Mounted Display
HOTAS	Hands-On-Throttle-And-Stick
HR	Heart Rate
HSD	Horizontal Situation Display
HUD	Head-Up Display
Hz	Hertz
IAS	Indicated Airspeed
IFA	In-Flight Alignment
IFF	Identify - Friend or Foe
IFR	Instrument Flight Rules

LIST OF SYMBOLS AND ABBREVIATIONS (Cont'd)

IIR	Imaging Infrared
ILS	Instrument Landing System
IMFK	Integrated Multifunction Keyboard
INS	Inertial Navigation System
IR	Infrared
JTIDS	Joint Tactical Information Distribution System
LC	Liquid Crystal
LD	Laser Display
LED	Light Emitting Diode
LLLTV	Low-Light-Level TV
LOAL	Lock-On After Launch
LOBL	Lock-On Before Launch
LRU	Line Replaceable Unit
LSI	Large Scale Integration
MFCU	Multifunction Control Unit
MFD	Multifunction Display
MLS	Microwave Landing System
MMD	Master Monitor Display
MMD	Multimode Display
MOS	Metal Oxide Semiconductor
MPD	Multipurpose Display
MRI	Medium Range Intercept
MSI	Medium Scale Integration
NAV	Navigation

LIST OF SYMBOLS AND ABBREVIATIONS (Cont'd)

nm	Nautical mile
P_{300}	A late component of an event-related potential
PAL	Permissive Action Link
PLD	Plasma Device
POL	Petroleum, Oil, Lubricant
R	Range
RBGM	Real Beam Ground Map
RHAWS	Radar Homing And Warning System
ROE	Rules of Engagement
RP	Readiness Potential
RTU	Remote Terminal Unit
S/A	Surface-to-Air
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SIF	Select Identification Feature
SMS	Store Management System
TA	Terrain Avoidance
TACAIR	Tactical Air Power
TACAN	Tactical Air Navigation
TACS	Tactical Air Control System
TDMA	Time Division Multiple Access
TERCOM	Terrain Contour Matching
TF	Terrain Following
TFR	Terrain Following Radar

LIST OF SYMBOLS AND ABBREVIATIONS (Cont'd)

TV	Television
UFC	Up-Front Control
UHF	Ultra High Frequency
VACQ	Vertical Acquisition
VAS	Voice Actuated System
VEL	Velocity
Vertex	Midline Site For Recording Brain Electrical Activity, Denoted C_z
VSD	Vertical Situation Display

PREFACE

This report presents the results of a study entitled "The Application of Biocybernetic Techniques to Enhance Pilot Performance During Tactical Missions." The research was conducted by the McDonnell Douglas Astronautics Company-St. Louis Division for the Defense Advanced Research Projects Agency (DARPA) under contract MDA-903-78-C-0181. The preparation of a second document - "Proceedings of the DARPA Conference on Biocybernetic Applications for Military Systems," Chicago, April 1978 - also was supported by this contract.

We acknowledge the assistance of Dr. Craig I. Fields, Senior Program Manager, Cybernetics Technology Office of the Defense Advanced Research Projects Agency.

1.0 ABSTRACT

This report describes a rather novel means of enhancing man's performance in highly complex, crew station environments. Specifically, we have related the benefits of on-line evaluation of physiological data to projected mission requirements for a 1990 tactical aircraft.

The salient role that tactical air power must continue to play in the structure of U.S. defense forces has engendered a sophisticated technological approach to weapon system development. Therefore, we begin with an overview of the components of a "high technology" weapon system - real-time command and control, advanced crew station and avionics design, effective defense suppression, sensor aided target acquisition, and precision-guided ordnance. Although a reliance upon advanced technology and a trend toward greater automation of aircraft functions are clearly evident, the importance of the human element should not be underestimated. This is especially true if the system is to retain the capacity to anticipate and respond to unpredictable threats. Herein lies the present dilemma. Man-in-the-loop assures that tactical aircraft will have an inherent flexibility. However, if man is unable to perform increasingly complex tasks both rapidly and accurately under all combat situations, he may severely limit, and perhaps even undermine, the inventive technology of the system he controls.

It may be possible to solve this problem by taking advantage of the same improvements in digital computation and signal processing that currently influence hardware development. That is, we may enhance the pilot's effectiveness if we monitor momentary fluctuations in attentiveness and in his

ability to process information and make appropriate decisions. The report summarizes research which has demonstrated that these mental activities are manifest in distinct electrophysiological signals, and that such signals, recorded noninvasively and unobtrusively, can be analyzed and interpreted in real-time. On this basis, we suggest that the central computer onboard the aircraft may be able to determine:

- o when the pilot is inattentive,
- o when visual or auditory information has not been processed,
- o when the pilot is task-loaded to the extent that he is unable to accept additional duties,
- o when the pilot lacks confidence in a decision he has made.

For a variety of mission segments we then outline the courses of action which can be taken to unburden or assist the pilot if biological signal processing has forewarned an imminent deterioration in his capacity to perform. The actions include, among others:

- o redistributing task responsibilities,
- o reducing the complexity of or "decluttering" information displays, especially the HUD,
- o cueing the pilot to attend to critical flight, weapons, and target data,
- o displaying adaptive decision aids which present weighted recommendations for mission-related strategies, particularly with respect to fire control functions,
- o furnishing remedial "checklists,"
- o optimizing the physical characteristics (e.g., contrast, focus, etc.) of imagery and symbolic presentations.

The recording and analysis of electrophysiological data also may permit a direct coupling of the pilot with aircraft subsystems from a control standpoint. At issue is whether it will be possible to interpret bioelectric patterns related to different thought commands, whereby the pilot can "think" to activate control surfaces.

We are aware that a great deal more must be accomplished (in computer technology, software development, and the design of physiological monitoring equipment) before it is both feasible and practical to apply biocybernetic techniques in dynamic, operational environments. Nonetheless, we have attempted to clarify important basic research issues and to recommend reasonable priorities for future investigations.

2.0 INTRODUCTION

Generally stated, our purpose has been to assess the impact of applying biocybernetic[1] techniques to improve human performance and thus enhance system effectiveness. We have made several assumptions in undertaking this assessement.

- o The human operator is and will remain an integral component of evolving computer-based systems.
- o These advanced systems will be adaptive, that is, the distribution of responsibilities between the operator and the system will be modified as circumstances change.

The computer-based system with which we are concerned is a generic tactical aircraft, and the human operator in this instance is more commonly referred to as a pilot. With respect to the data requirements for implementing adaptive procedures, we find that digital avionics programs within the Air Force and Navy are providing the means for a reliable and efficient flow of information about the current status of aircraft subsystems. Via external sensing, the pilot also will be apprised of the changing posture of the mission.

[1] The term denotes a real-time communication link between a human operator and the system he controls, that is based upon the physiological activity which is recorded as the operator performs assigned tasks.

Rapidly occurring developments in digital computation, data-busing, electronic circuitry, display generation, and input/output technology have created a trend toward greater automation. This will reduce the extent to which the pilot participates in housekeeping functions (i.e., navigation, subsystems monitoring, communications, and aircraft control), thereby allowing him to attend more closely to mission-related activities (i.e., detection, location, identification, decision, execution, and assessment). The pilot will, of course, play a direct role in any housekeeping function if alerted of a subsystem failure.

While the communication link from subsystem to computer is impressive indeed, we may ask whether comparable means are available for the pilot to convey status information to the computer. Status in this context refers to momentary fluctuations in attentiveness or in the ability to process information and make appropriate decisions. An operator usually communicates with a computer via manual responses or perhaps a small vocabulary of verbal responses. It is unlikely that these inputs are sufficiently sensitive to the types of momentary fluctuations mentioned above. And even if overt behavioral measures could provide such information, the process of supplying it on demand might prove extremely disruptive to critical mission-related tasks.

The program of biocybernetics research sponsored by DARPA since 1974 has attempted to alleviate the imbalance in the flow of status information by adding a communication channel from the operator to the computer. In describing the program, Donchin (1979) states:

"A channel carrying psychophysiological data (unobtrusively) acquired from the operator can supply the adaptive controller with at least part of the necessary information. The program thus assumes that mental activities manifest themselves in a variety of physiological signals. It further assumes that it is possible to make strong inferences about mental activity from such signals." (p. 3)

We believe that the virtue of this communication channel is not limited to the conveyance of status information for the purpose of effecting more or less automation. Rather, we also envisage, among other applications, a direct coupling of the pilot to aircraft subsystems from a control standpoint, such as through "thought" commands.

In this report, we examine whether the pilot's ability to satisfy tactical mission requirements can be enhanced if electrophysiological manifestations of brain function are processed by the central computer. We discuss quick-reaction situations, where the crew member is vulnerable and where performance accuracy or the speed of response may be improved. While brain electrical activity is emphasized, we consider other biological signals as well. These include peripheral psychophysiological responses and aspects of ocular behavior.

We have concentrated on pilot tasks associated with (a) the extraction of displayed information and auditory messages, (b) decision-making based upon subsequent processing of these inputs, and (c) control activation. Moreover, the pilot tasks we describe in detail were chosen because they are very difficult and/or are critical to the success of the mission, or because they occur during periods of high workload.

The next section of the report summarizes relevant "ground rules" for biocybernetic applications in a 1990 time period. As described previously (Gomer and Youngling, 1978), there are significant technical difficulties to be overcome before closed-loop concepts can be incorporated in operational settings. We feel that the time frame which has been adopted is reasonable, in view of the necessity for long-term planning. Sections 4 and 5 compare general mission requirements for the principal mission types and outline the information needs of the pilot, respectively. Three major subsections comprise Section 6. The first presents time line analyses of pilot tasks for a postulated escort mission. This is followed by a discussion of the particular categories of biological signals which, when interpreted by the computer, offer the most promise for improving task performance. Finally, biocybernetic applications are presented in a matrix format for each of thirteen integrated mission segments. Section 7 then offers conclusions and recommendations.

3.0 AN OVERVIEW OF MISSION TYPES AND PROJECTED TECHNOLOGY ADVANCES FOR TACTICAL AIRCRAFT

This summary information is intended to provide a framework for later discussions of pilot tasks and potential biocybernetic applications.

In general, we have assumed a Central European Theatre (CET), and this has influenced mission requirements, projected weapons, and aircrew functions. We also have recognized the trend toward one-man aircraft, due to reduced procurement, operating, and training costs, and the fact that fewer personnel are exposed to combat. We assume that vehicle characteristics will be typical of a two engine high performance aircraft (perhaps with direct force flight control). Ordnance should consist principally of stand-off type weapons, and command, control, and communication (C^3) should encompass: Airborne Warning and Control Systems (AWACS), Global Positioning Satellite (GPS), and Joint Tactical Information Distribution System (JTIDS).

We believe that advanced crew stations will be developed with a concern for efficient information flow between the pilot and the various aircraft subsystems (cf. Mills et al., 1978). Figures 3.1 and 3.2 illustrate the essential elements of such a crew station. Included will be:

(1) Vertical Situation Display (VSD) - presents attitude and position information in the vertical plane, also predictive or command symbology for all flight phases,

(2) Horizontal Situation Display (HSD) - provides geographic information in the form of terrain images, computer generated navigational maps and supporting symbology, and tactics,

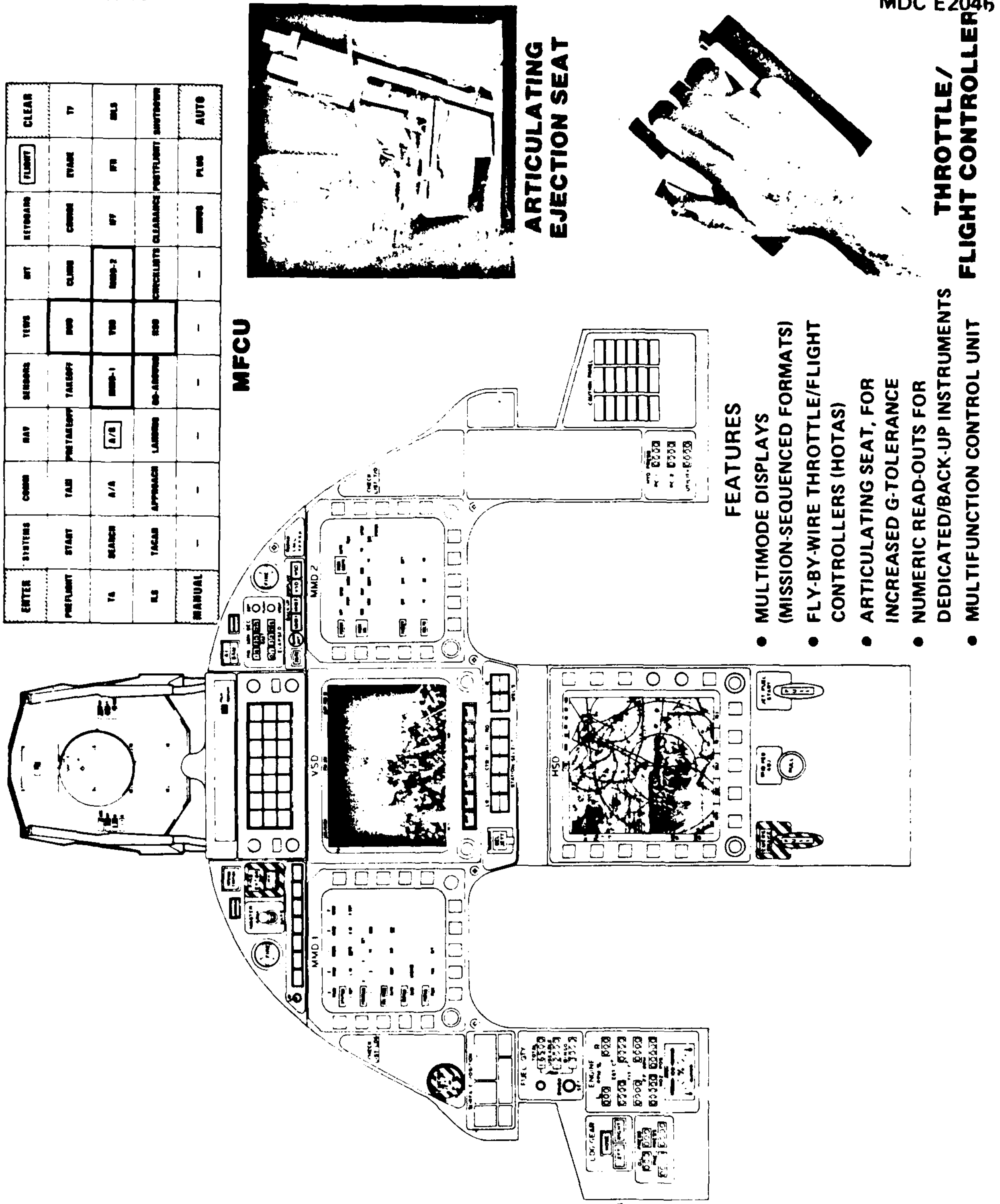
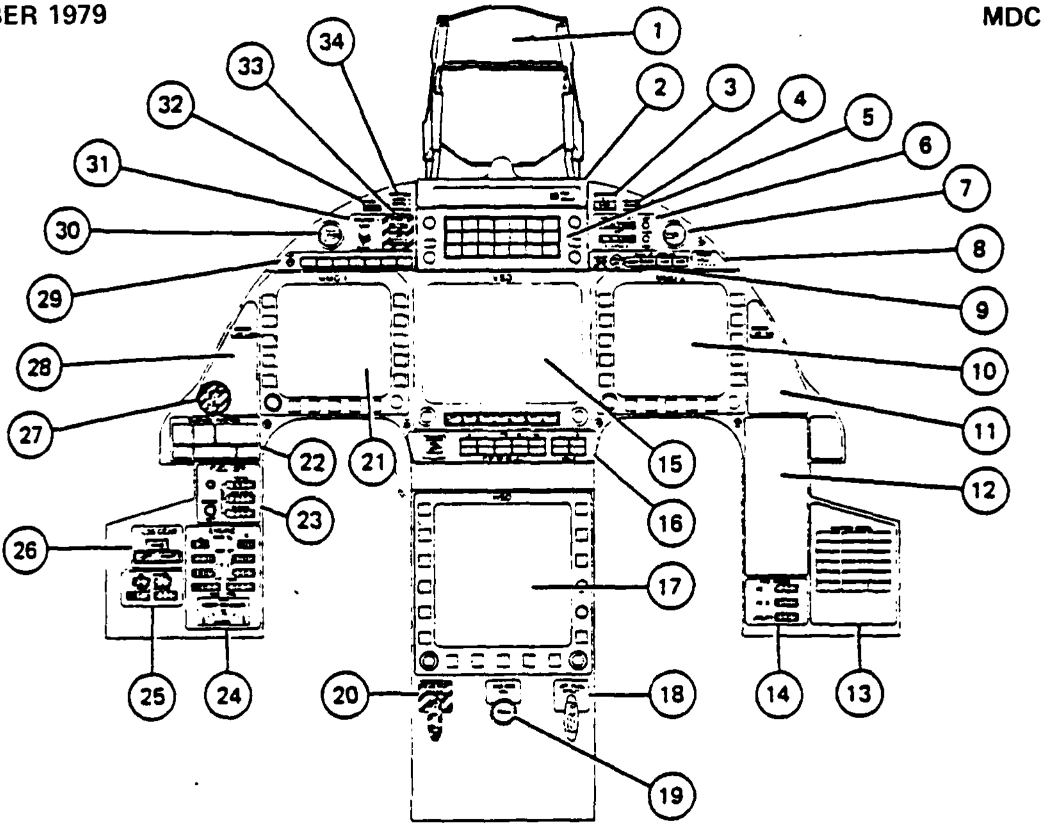


FIGURE 3.1 INTEGRATED CREW STATION CONCEPT FOR A 1990 TACTICAL AIRCRAFT.



1. Head Up Display
2. Head Up Display Camera
3. Threat Alert
4. Canopy Alert
5. CNI/ECM/HUD Control
6. Digital Clock
7. R/H Engine Fire Alert and Extinguisher Button
8. Radio Call Number
9. Back Up Display Select Panel
10. Multimode Display No. 2
11. Takeoff Check List and Spare
12. Spare Panel
13. Caution and Advisory Panel
14. Hydraulic Pressure
15. Vertical Situation Display/Tactical Display (Multimode)
16. Armament Station Select/Selective Jettison Panel
17. Horizontal Situation Display and Moving Map (Multimode)
18. Jet Fuel Starter
19. Rudder Pedal Adjustment
20. Emergency Brake
21. Multimode Display No. 1
22. Surface Position Indicators (Ref)
23. Fuel Quantity Panel (Ref)
24. Critical Engine Status (Ref)
25. Oil and Pneumatic Pressure
26. Landing Gear Position Indicator
27. Clear All Stores Emergency Jettison
28. Landing Check List and Spare
29. Mode Advisory Panel
30. L/H Engine Fire Alert and Extinguisher Button
31. Armament Master Arm Switch
32. Landing Gear Alert
33. Fire Extinguisher Arm Switch
34. Master Caution

FIGURE 3.2 DESCRIPTIONS OF THE INSTRUMENTS DEPICTED IN FIGURE 3.1.

(3) Multipurpose Displays (MPDs) - present system malfunctions automatically; operator selects via keyboard the information he desires (e.g., engine parameters, flight checklists, target designations, weapons status, sensor FOV, etc.),

(4) Head-Up Display (HUD) - presents weapons delivery and flight information, also limited video,

(5) Helmet-Mounted Display (HMD) - a virtual image display (as is the HUD) which also presents weapons delivery and flight information; however, it obviates the usual requirement of a fixed display location,

(6) Multifunction Control Unit (MFCU) - allows the pilot to sequence display presentations via keyboard inputs,

(7) Hands-On-Throttle-And-Stick (HOTAS) Controls - fly-by-wire, with critical subsystem (particularly weapons) controls integrated directly into the stick and throttle.

Growing alarm over the task demands imposed on the pilot and severe space limitations within the crew stations of existing tactical aircraft have forced engineers to discard a design philosophy which prescribes the use of dedicated, single-purpose instruments. An accelerated obsolescence of this conventional approach to crew station design and a new emphasis on multipurpose displays and keyboards have been brought about by remarkable developments in two areas: digital avionics and programmable electronic display devices. Large scale integration (LSI) technology has produced the necessary microcircuit/ microprocessor electronics to create an extremely flexible display generation capability. Raster-scan graphics can be used to generate realistic and varied synthetic visual scenes, and they afford an ease of mixing display symbology with the outputs of imaging sensors such as radar, low-light-level TV, and forward looking infrared. Display presentations can be limited (in theory) to those sources of information which are most relevant at a specific time period in the mission. Moreover, the sequencing of presentations can be controlled by the particular computer program(s) in operation and by the crew member's keyboard inputs.

While numerous display developments are in progress that offer great promise for the 1990 time frame we have adopted, the cathode ray tube (CRT) in all likelihood will remain preeminent. It has a superb capability for presenting almost unlimited formats (including video).

3.1 MISSION TYPES

Tactical Air Power (TACAIR) recognizes three primary missions to accomplish the objective of successfully waging war. The missions are Close Air Support (CAS), Air Interdiction (AI), and Counter Air (CA). Although there are other TACAIR missions, such as Reconnaissance and Electronic Warfare, they generally are conceived to be supportive of offensive air-to-air and air-to-ground missions. Mission definitions are as follows:

Close Air Support - Air action against hostile ground targets that are in close proximity to friendly ground forces. This requires detailed integration of each air mission with the battle activities and movements of those forces.

Air Interdiction - Air operations conducted to destroy, neutralize or delay the enemy's military potential before it can be brought to bear against friendly forces. These operations are conducted at such distances from friendly forces that detailed integration of air and ground activities is not required.

Counter Air - Air operations conducted to attain or maintain a desired degree of air superiority by the destruction or neutralization of enemy air forces. Both offensive and defensive air actions are involved. Offensive actions range throughout enemy territory and generally are conducted at the initiative of the friendly forces. Defensive operations are conducted near to or over friendly territory and usually are reactive to the initiative of the enemy air forces.

Figure 3.3 summarizes the scope of TACAIR's three primary missions. Obviously, a large number of mission profiles will emerge for each mission type, given the unpredictable nature of enemy operations and the broad range of weapons, sensors, and C^3 systems employed by friendly air forces. Consequently, comprehensive yet representative profiles were developed for the three missions.

We have chosen to concentrate on the basic elements of each mission and to avoid excessive concern for mission details that infrequently impact aircrew tasks. For example, a pilot does not particularly care whether he penetrates at 0.85 or 0.92 Mach, at 25,000 or 29,000 ft, or whether he pulls 6.2 or 7.1 g's. These are operational techniques that take advantage of particular design features and overall aircraft performance. Once a pilot is

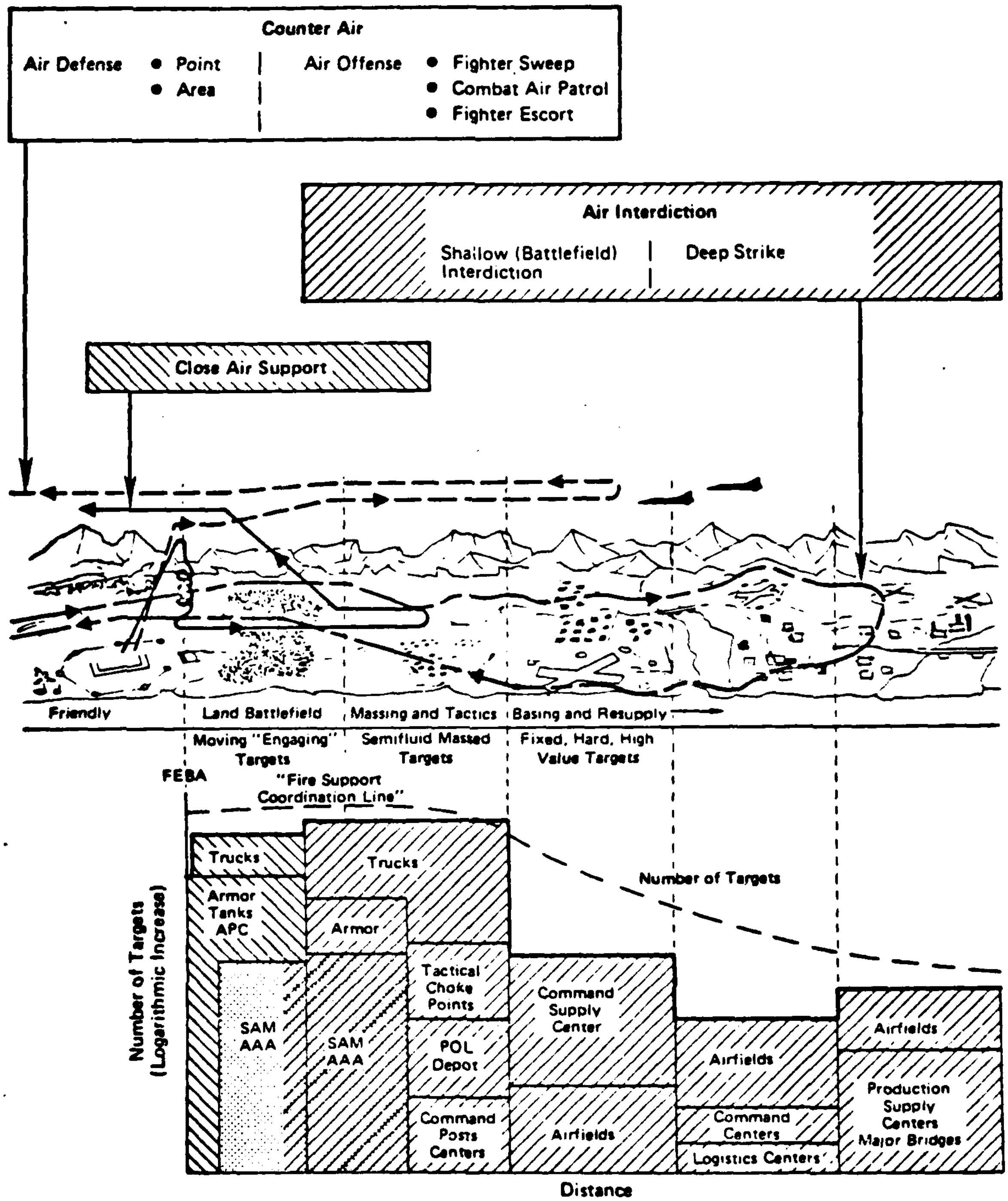


FIGURE 3.3 PICTORIAL REPRESENTATION OF THE THREE TACAIR MISSIONS.

thoroughly familiar with an aircraft he usually develops "rules of thumb" to cover the situations most commonly encountered. A pilot frequently will fly mission segments, such as low level routes, at airspeeds which are even tenths of a Mach (0.7, 0.8, or 0.9) or multiples of 60 knots (420, 480, 540). This is done in lieu of best cruise or other optimum speeds because it facilitates solving in-flight timing problems, an important parameter in all offensive air missions.

The previous example illustrated that mission timing can be more important than optimum penetration speed. Many other examples are possible that would further contrast pilot and aircraft design priorities. The mission profiles that follow emphasize the pilot priorities, especially in terms of decision-making functions and information needs.

General mission requirements are identified in Figure 3.4 for pre-flight, in-flight, and post-flight phases. Representative mission profiles were constructed from these requirements and are illustrated in Figures 3.5 through 3.7 for Close Air Support, Air Interdiction, and Counter Air missions, respectively. A detailed comparison of mission requirements for the three mission types is presented in Section 4.0.

Although we have considered the mission requirements individually, they overlap significantly in operational situations.

1. Pre-Flight - All aircrew functions leading up to and including takeoff.

    1.1 Mission Planning
    1.2 Preflight
    1.3 Start and System Checks
    1.4 Taxi
    1.5 Arming
    1.6 Takeoff

2. In-Flight - All flight activities beginning with climb and concluding at the termination of the landing roll.

    2.1 Climb to Level-Off
    2.2 Cruise
    2.3 Loiter
    2.4 Rendezvous and Air-to-Air Refueling (AAR)
    2.5 Coordination
    2.6 Mission Rendezvous
    2.7 Penetration
    2.8 Threat Warning
    2.9 Detection
    2.10 Location
    2.11 Identification
    2.12 Decision
    2.13 Execution
    2.14 Assessment
    2.15 Termination
    2.16 Egress
    2.17 Cruise
    2.18 Rendezvous and Air-to-Air Refueling (AAR)
    2.19 Reengage
    2.20 Return to Base
    2.21 Descent
    2.22 Approach
    2.23 Landing

3. Post-Flight - All mission-related activities beginning after the completion of the landing roll and ending when the aircrew is free to perform other duties or pursue personal interests.

    3.1 De-arm
    3.2 Taxi
    3.3 System Checks
    3.4 Shutdown
    3.5 Post-Flight
    3.6 Debrief

FIGURE 3.4 GENERAL MISSION REQUIREMENTS FOR PRE-FLIGHT, IN-FLIGHT, AND POST-FLIGHT PHASES.

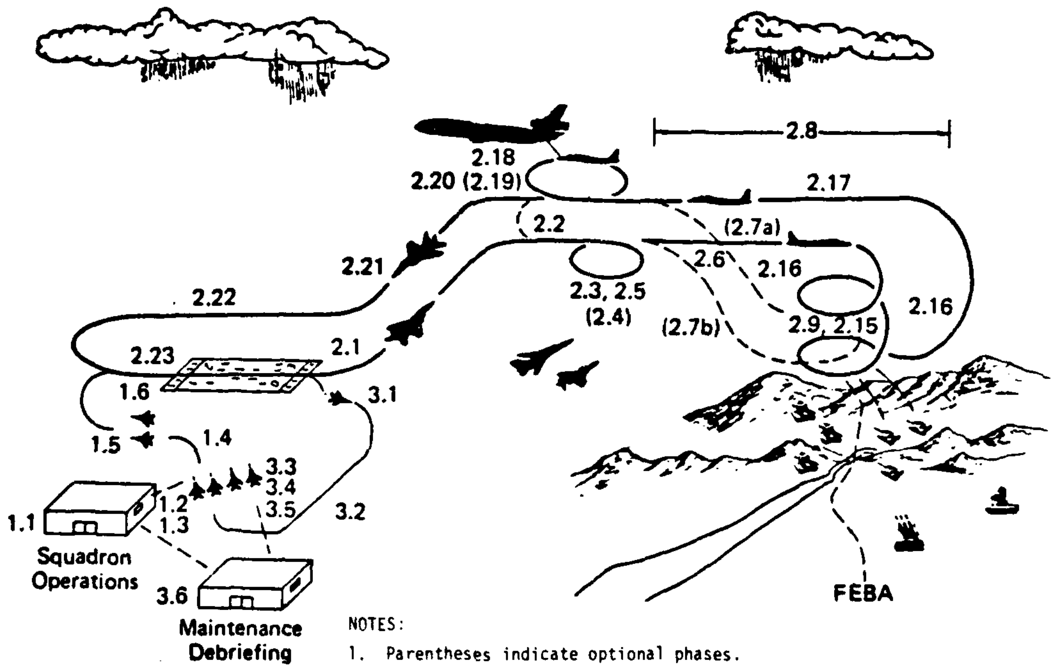
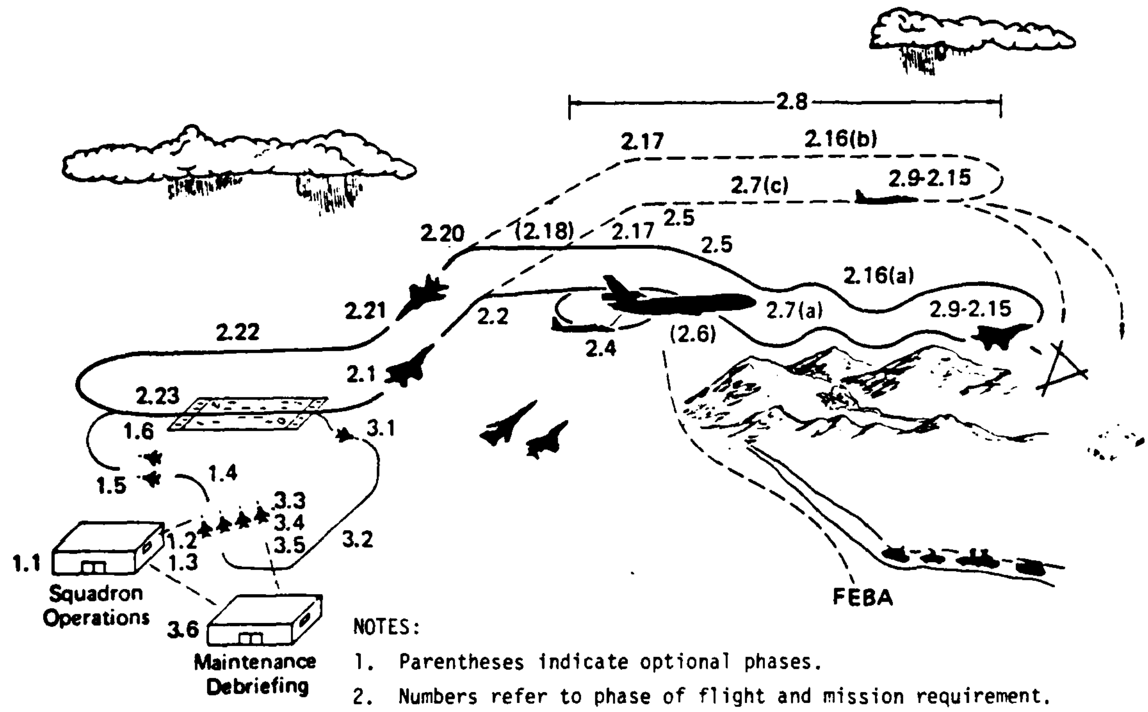


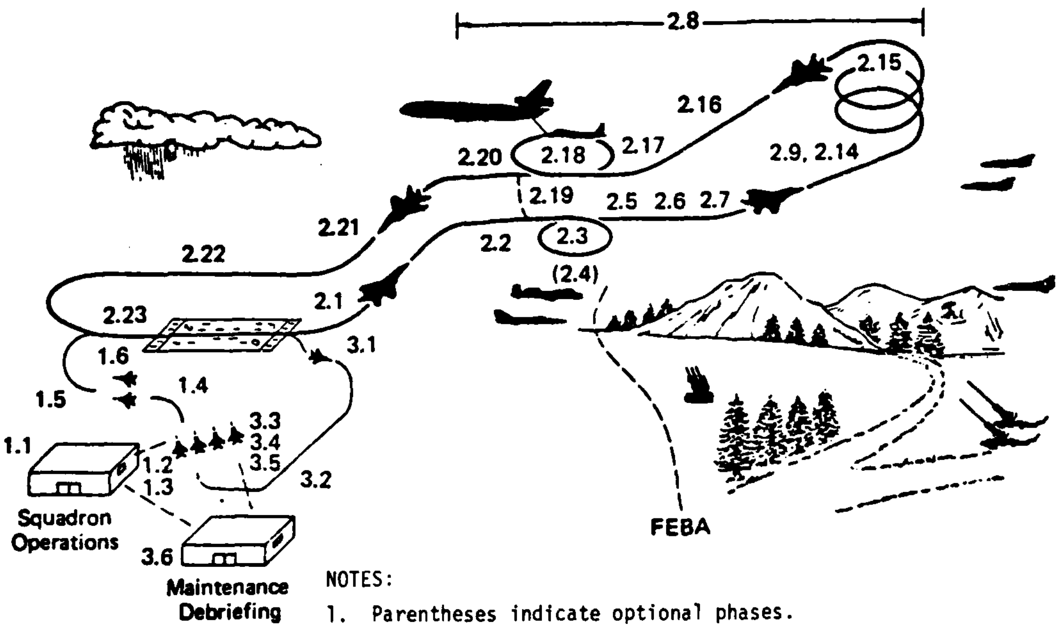
FIGURE 3.5 MISSION PROFILE FOR CLOSE AIR SUPPORT.



NOTES:

1. Parentheses indicate optional phases.
2. Numbers refer to phase of flight and mission requirement.

FIGURE 3.6 MISSION PROFILE FOR AIR INTERDICTION.



NOTES:

1. Parentheses indicate optional phases.
2. Numbers refer to phase of flight and mission requirement.

FIGURE 3.7 MISSION PROFILE FOR COUNTER AIR.

3.2 TECHNOLOGY ADVANCES

3.2.1 Weapons - The CET's defenses, weather, terrain, and target characteristics (size, mobility, signature) compromise the effectiveness of many weapons which currently are operational (cf. Levine, Beideman, and Youngling, 1978). Therefore, new concepts are needed. Stand-off weapons, both unitary and dispenser types, with midcourse and terminal guidance offer one of the most feasible solutions. Figure 3.8 summarizes the characteristics of various guidance options. These guidance systems also can be used in combination. For example, midcourse guidance can be inertial while terminal guidance can be imaging infrared (IIR) with data link lock-on.

It is important to emphasize that the key features of future weapons are that they be stand-off and that they possess accurate guidance and control. The net results are to increase survivability and effectiveness and to reduce losses and the resources required to destroy a target.

Figure 3.9 defines the various air-to-air missiles that influence pilot tasks. The physical characteristics are listed, as are the system components associated with a successful missile deployment. Important to the crew station designer are the cockpit components that are required to launch each missile. The basic purpose of each missile has been provided in the "Remarks" column.

Figures 3.10 and 3.11 present similar information for air-to-surface ballistic weapons and air-to-surface missiles, respectively.

Generic Guidance Type	Characteristics: Adverse Weather	Fixed Targets	Moving Targets	* LOBL	** LOAL	Launch and Leave
Laser Seeker	—	√	√	√	√	—
EO Tracker (Edge, Centroid, Correlation)						
Lock On Before Launch	—	√	√	√	—	√
Data Link Lock On	—	√	√	—	√	√
IIR Tracker (Edge, Centroid, Correlation)						
Lock On Before Launch	—	√	√	√	—	√
Data Link Lock On	—	√	√	—	√	√
IR/Radiometric Seekers (Passive)	√	√	√		√	√
Radar						
Contrast Trackers	√	√	√	√	√	√
SAR *Line of Sight*	√	√	√	—	√	—
SAR Azimuth/Range Coincidence	√	√	√	—	√	—
Radar Correlation	√	√	—	√	√	√
IR/Radiometric Correlators	√	√		√	√	√
Terrain Correlators (TERCOM)	√	√		√	√	√
Antiradiation	√	√		√		√
Inertial	√	√		√	√	√

*Lock-on before launch
**Lock-on after launch

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FIGURE 3.8 GUIDANCE SYSTEMS AND THEIR CHARACTERISTICS.

Designation	Characteristics	Aircraft System Components Required	Cockpit Components Required	Remarks
1. BDM	Integral rocket/ramjet; homing	Unknown	Unknown	Bomber defense missile for B-1
2. BRAZO	Radar homing	RHAWS; Stores release system	MMD, SMS, CNTRLS, release switch	Antiradiation missile
3. FALCON (AIM-4F)	7.1' length; 140 lb; semi-active pulse radar homing; Mach 3; 5 nm range	None; Stores release system	SMS; release switch; slew control	Used on F-106; AIM-4G has IR guidance
4. PHOENIX (AIM-54A)	13.0' length; 1000 lb; semi-active radar homing	Radar; Stores release system	MMD, SMS; release switch	For use on F-14A
5. Genie	9.6' length; 800 lb; unguided; nuclear warhead	Stores release system	Multimode display; PAL nuclear armamant panel; release switch; radar hand controller	Used on F-106
6. Sidewinder (AIM-9E-L)	Approximately 10' length; 180 lb; infrared homing	Stores release system	Aural tone, HUD, SMS, slew control; release switch	Various capabilities up to all aspect
7. Sparrow (AIM-7E, F)	12.0' length; 450-500 lb; semi-active (cw) radar homing; 12-24 nm range	Radar, mission computer, Stores release system	MMD, SMS, release switch	Used on F-4, F-14, F-15 and F-18
8. Guns: 20MM	High velocity projectiles	Radar, mission computer, Stores release system	HUD; release switch	
9. AMRAAM	Command inertial mid-course, active radar terminal. Physical characteristics undefined.	Undefined	Goal: Compatible with existing sparrow/sidewinder switchology	Goal: Compatible with F-14, F-15, F-16 & F-18 aircraft. (In competition stage)

FIGURE 3.9 TYPES OF AIR-TO-AIR MISSILES.

Designation	Characteristics	Aircraft System Components Required	Cockpit Components Required	Remarks
1. Modular Glide Bomb (CBU-15)	Winged 2000 lb bomb; modules	Stores release system	Slew control, HUD or sight; release switch	Could also use DME or laser guidance
2. MK-82	500 lb; 86 in.	Stores release system	Aiming sight or HUD; release switch	General purpose munition
3. MK-84	2000 lb; 12' 8" length	Stores release system	Aiming sight or HUD; release switch	General purpose munition
4. Guns: 20MM 30MM	High explosive incendiary	Gun system	HUD or sight; release switch	
5. MK-117	750 lb; 90 in.	Stores release system	HUD or sight; release switch	General purpose munition
6. KMU-351 (MK-84 laser guided)	2052 lb; 14' length	Stores release system	Laser detector; HUD or sight; release switch	
7. MK-82 Snakeye	560 lb; 84 in.	Stores release system	HUD or sight; release switch	High drag version of MK-82
8. CBU-30/A; 90.4 in.	385 lb	Stores release system	HUD or sight; release switch	Cluster munition loaded with 1280 BLU-39/B23 bomblets
9. CBU-24, 49, 52, 58, and 71	820 lb; clam shell; 88 in.	Stores release system	HUD or sight; release switch	Loaded with 670 bomblets, except CBU-52, which has 217 bomblets
10. Rockeye II	485 lb; 93 in.	Stores release system	HUD or sight; release switch	Dispenser weapon loaded with 247 MK-118 MODO bomblets
11. BLU-1C/B, 27/B Fire Bomb	100 gals; 143 in.	Stores release system	HUD or sight; release switch	Filled with incendigel

FIGURE 3.10 TYPES OF AIR-TO-SURFACE BALLISTIC WEAPONS.

Designation	Characteristics	Aircraft System Components Required	Cockpit Components Required	Remarks
1. ALCM (ACM-86)	19' length; 2800 lb; inertial/tercom	Inertial navigation system; Stores release system	Control head, SMS; release switch	Strategic nuclear role with B-1 and B-52
2. Bullpup A (ACM-12B)	11.0' length; 571 lb; command guidance; 250 lb warhead; 6 nm range	Unknown	Slew control; release switch	Being phased out of inventory
3. HARM (ACM-88A)	13.7' length; 770 lb; radar homing	RHAWS; Stores release system	MMD; SMS; release switch	High velocity anti-radiation
4. Harpoon (ACM-84A)	12.5' length; 1170 lb; active radar; 50+ NM range	Stores release system	MMD; release switch	Anti-ship missile.
5. Maverick (ACM-65A/B)	8.2' length; 475 lb; television guided	Stores release system	MMD; controls, slew control; release switch	Laser and imaging infrared Maverick under development. Useful against tanks
6. Shrike (ACM-45B)	10.0' length; 400 lb; passive radar homing	RHAWS; Stores release system	Aural tone; release switch	Used on Wild Weasel aircraft (F-105G and F-4G)
7. SRAM (ACM-69A)	14.0' length; 2230 lb; inertial guidance; 120 nm range	Unknown	Release switch	Short range attack missile for B-1, FB-111, and late Model B-52's
8. Standard ARM (ACM-78C/D)	14.9' length; 1355 lb; radar homing	RHAWS; Stores release system	MMD; lock on indication; release switch	Anti-radiation missile
9. Walleye 1, 2	11.3-13.25' length; 2400 lb; television data link	Data link; Stores release system	MMD; slew control; communication CNTRL head; release switch	Unpowered TV guided glide weapon

FIGURE 3.11 TYPES OF AIR-TO-SURFACE MISSILES.

3.2.2 Avionics - The reduction in the cost of digital circuitry and the advantages of expandable memory are responsible for an increase in the use of digital computers onboard military aircraft. Most importantly, the avionics are more integrated, with the various subsystems under the control of higher level systems which, in turn, are under the control of the pilot. By effective interconnection of subsystems workload can be reduced, permitting the pilot to concentrate on those tasks which the central computer cannot handle effectively.

The advances in electronics will result in more accurate navigation, improved night and adverse weather target detection, jam resistant communications, and more effective countermeasures. The largest payoff may be in terms of better command, control and communication (C^3) systems. The programs most likely to affect aircraft systems and crew information requirements are the Joint Tactical Information Distribution System (JTIDS) and the Airborne Warning and Control System (AWACS). Although not directly a C^3 program, the Global Positioning System (GPS) may interface with JTIDS for navigation and blind navigation bombing purposes.

A summary of anticipated avionics improvements is shown in Figure 3.12, with reference to the Air Force Digital Avionics Information System (DAIS).

3.2.2.1 Sensors - The information which is displayed during various phases of the mission is derived from two sources: (a) real-time sensors and (b) the *a priori* data base stored in the aircraft computers before takeoff. In general, those data which are retrieved assist the pilot in performing monitoring, navigation, threat location, and target acquisition functions.

Function	Equipment Type	Anticipated Advances
NAV	Inertial	Strapdown; improved gimballed systems
	ADC	Computations performed in processor
	TACAN, ILS, ADF	Weight, size, power consumption
	GPS, OMEGA	Will become operational
	Hybrids	GPS/inertial available
COM		MSI, LSI; Shared Antenna ; Modulation techniques
	JTIDS	Will become operational
	IFF	Improved performance, cost reductions
ECM		Power management
Air/Ground Attack	Lasers	Laser target seekers will become operational
	FLIR	Reduced costs, weight, size; improved display
	FLR	Improved performance, reliability
C/D	Controls & Displays	Current displays and controls will be replaced by computer-driven MPD plus IMFK
Processing	Processors	LSI technology and microprocessors with large central processing capability
		BITE contained within microprocessors
		MOS (metal oxide semiconductors) Bipolar Schottky transistor-transistor logic
Power Supply		Central power supply core element
Interface Equipment	BCIU, RTU	Integrated within sensor or processor

FIGURE 3.12 ANTICIPATED AVIONICS ADVANCES (WITH REFERENCE TO DAIS).

The sensors, on the other hand, provide essential information for all housekeeping and mission-related functions, particularly navigation, communication, threat detection/ location, and the execution of air-to-air or air-to-ground attack.

Representative sensors onboard the aircraft include:

- o multimode radar and forward looking EO or IR sensors for target recognition; laser designator/ranger/tracker for attack,
- o imaging seekers for missile guidance (see Figure 3.8) (implied is the dedicated fire control computer for directing these seekers to the aimpoint coordinates available from the target acquisition sensors),
- o navigational sensors for INS, TACAN, and GPS,
- o radar and laser threat (ground and air) warning sensors, IFF threat identification receivers, and data-link receivers (e.g., JTIDS).

We should mention that a more inclusive listing would encompass the feedback devices which are used to monitor the status of the various aircraft subsystems. By restricting our focus to those baseline sensors listed above, however, we can describe their characteristics in greater detail (see Figure 3.13).

3.2.2.2 Electronic Displays - In the next two sections (4 and 5) of this report, the mission requirements and the associated information needs of the pilot are described for the reader. These sections demonstrate that flexibility in display generation is essential to satisfy future mission objectives. The pilot must be able to select, or be provided automatically, integrated information which is updated or changed accordingly across specific time periods in the mission.

SENSOR	TYPE OF INFORMATION PROVIDED	FORMAT IN WHICH INFORMATION IS DISPLAYED
AIR-TO-GROUND RADAR		
o Real Beam Ground Map (RBGM)	Video Imagery; Cursors; AZ and R Markers	Sector with R vs. AZ
o Doppler Beam Sharpened (DBS)	Video Imagery; Cursors; Sector - AZ and R Markers Patch - AZ and R Numerics	Sector or Patch
o Synthetic Aperture Radar (SAR)	Video Imagery; Cursors	Passing Scene Map or Track; EL vs. AZ
o Ground Moving Target Indication (GMTI)	Target Symbol on Ground Map Video; Designating Cursor	RBGM Sector, DBS Sector/Patch or SAR Map
o Air-to-Ground Ranging (AGR)	Target Symbol at Measured Slant Range; Numerical Readout of Range	Sector with R vs. AZ
o Terrain Following (TF)	Terrain Profile; Template of Desired Altitude	EL vs. Log R
o Terrain Avoidance (TA)	Video of Return Above Clearance Plane; Horizon Line Symbol	Sector with R vs. AZ

SENSOR	TYPE OF INFORMATION PROVIDED	FORMAT IN WHICH INFORMATION IS DISPLAYED
AIR-TO-AIR RADAR		
o Pulse Search o Velocity Search o Range While Searching o Track While Scanning	Target Symbols; Acquisition Symbol; AZ and EL Carets; Flight Symbology	R vs. AZ VEL vs. AZ
HIGH RESOLUTION TV	TV Imagery	EL vs. AZ
LOW-LIGHT-LEVEL TV (LLLTV)	TV Imagery	EL vs. AZ
FORWARD LOOKING INFRARED (FLIR)	8 to 11 μM Imagery	EL vs. AZ
MISSILE THERMAL IMAGING	8 to 11 μM Imagery	EL vs. AZ
MISSILE EO	TV Imagery	EL vs. AZ
EO TRACKER	TV Imagery	EL vs. AZ
IR TRACKER	3-5 μM Imagery; Hit/Miss Warning	EL vs. AZ
IR WARNING	Hit/Miss Video; Bearing of Missiles and Interceptor	Symbol on EL vs. AZ Display
LASER TRACKER	Direction of Line-of-Sight	Symbol on EL vs. AZ Display or on HUD
LASER OR RADAR WARNING	Hit/Miss Video; Bearing and Identification of Illuminator or Emitter	AZ vs. Lethal Range Rings; Threat Symbols

FIGURE 3.13 SENSOR CHARACTERISTICS.

We stated earlier that flexibility is afforded, in part, by the incorporation of multifunction display techniques. Our purpose in this subsection is to present a brief comparison of those electronic display media which will be competing for inclusion in tactical crew stations during the 1990s. Recall that Figures 3.1 and 3.2 illustrated the display units which will present visual information to the pilot. They consisted of:

o Multipurpose Displays (MPDs),

o Horizontal Situation Display (HSD),

o Vertical Situation Display (VSD),

o Head-Up Display (HUD),

o Helmet-Mounted Display (HMD).

Presentation media for alpha numerics, symbolic characters, graphics, and full video should include:

o Cathode Ray Tubes (CRTs),

o Liquid Crystals (LCs),

o Plasma Devices (PLDs),

o Light Emitting Diodes (LEDs),

o Electroluminescence Devices (ELs),

o Laser Displays (LDs),

o Electromechanical Devices (EMDs).

To allow a meaningful comparison of these display devices, consider the information formats and coding schemes (Figure 3.14) with respect to which the competing technologies will be assessed (see Figure 3.15). Other factors certainly must be taken into account when establishing evaluation criteria, and these are illustrated selectively in Figure 3.16.

A	-	On-off: legend
B	-	Alpha numerics: fixed alphabet
C_1	-	Characters (symbols and alpha numerics), raster or matrix generated: variable alphabet
C_2	-	Characters, stroke generated: variable alphabet
D	-	Graphics and characters: fixed format and alphabet
E_1	-	Graphics and characters, raster or matrix generated: variable format and alphabet
E_2	-	Graphics and characters, stroke generated: variable format and alphabet
F	-	Full video (or fixed image)
G	-	Color coding
H	-	Size coding
I	-	Depth coding
J	-	Time coding (typically a software problem)

FIGURE 3.14 INFORMATION FORMATS AND DISPLAY CODING SCHEMES.

DISPLAY TECHNOLOGIES

DISPLAY FORMAT TYPES (SEE FIGURE 3.14)	LD	EMD	EL	LED	PLD	LC	CRT
A	X	X		X	X	X	X
B	X	X	X	X	X	X	X
C_1	X			X	X	X	X
C_2	X						
D	X	X		X	X	X	X
E_1			X	X	X	X	X
E_2	X						X
F	X			?	?	X	X
G	X	X	X	?	?		?
H	X	?	X	X	X	X	X
I							
J	X	?	X	X	X	X	X

FIGURE 3.15 COMPARISON OF DISPLAY TECHNOLOGIES, WITH RESPECT TO INFORMATION FORMATS AND CODING SCHEMES.

PARAMETER	PLASMA PANEL	ELECTROLUMINESCENCE (THIN FILM)	LIGHT EMITTING DIODES	LIQUID CRYSTAL	CRT
Resolution	30-60 epi	20-50 epi, large panels 500 epi, small panels	30-50 epi	100 epi, large panels 588 epi, small panels	120-1600 epi
Brightness	>30-50 ft L	>30 ft L	>100 ft L	Ambient Dependent	>30-1000 ft L
Contrast	≥20:1 Binary	≥10:1 Full Video	100:1	20:1 Full Video	20:1 Full Video
Display Size	<1024 elements 17 inch sq (ac driven)	240 elements, 6 inch 500 elements, 1 inch	250 elements, 6 in. sq.	350 elements, 3.5 in. 600 elements, 1 in.	480-830 elements 1-25 inch sq.
Color	Primarily Neon Orange Full Color Possible	Phosphor Dependent Full Color Possible	Red; green and yellow also available	Primary Black/White but Contrasting Colors are Available	Phosphor Dependent, Discrete Colors Also
Power Requirements	200-300W	10W	1.5-2.0W/cm^2 @1.5-2.0 volts	5μw/cm^2 to 1.0 mW/cm^2 @3-15 volts	100 Watts
Thickness	<1 inch	<1 inch	<1 inch	<1 inch	≈12-18 inch
Weight	50 lbs	-	-	-	Up to 50 Lbs.
Environment	Rugged	Rugged	Rugged	Rugged but Temperature Limits	Ruggedized
Aspect Viewing	Wide Aspect	Uniform, Wide Aspect	Slight Gain But Basically Uniform	Restricted	Uniform Wide
Time Constants	Std. Video (dc driven)	Compatible With Std. Video	Compatible With Std. Video	10-500 ms (with scan converter LC can display std. video)	3-10MHz Std. Video
Storage/ Refresh	yes (ac driven) no (dc driven)	Yes, but is configuration dependent	No	Limited Storage	None (storage CRTs are available)
Reliability/ Maintainability	100,000 hrs LRU	1,000 to 10,000 hrs, LRU	10,000 to 100,000 hrs, LRU	20,000 hrs, LRU	15 to 15,000 hrs, LRU
Status	Operational/ Commercially Available	Laboratory Demonstration Models	Commercially Available/ Operational	Operational/Laboratory Demonstration Models	Operational

FIGURE 3.16 EVALUATION PARAMETERS AND CORRESPONDING PERFORMANCES OF SELECTED DISPLAY DEVICES.

The CRT will probably remain the fundamental display medium in the 1990s, because of its versatility in generating data for all display units listed above (i.e., MPD, HSD, VSD, HUD, HMD). However, as new display media are developed (e.g., electrophoretic, magnetic particle, and electrochromatic devices) the pilot's information needs, which translate to display formats and codes, must be considered as the most significant evaluation criterion.

3.2.2.3 Multifunction Control Unit - Multifunction switches, a relatively new concept in control technology (see Figure 3.1), are a counterpart of computer generated multifunction displays. They may be thought of as versatile sets of switch contacts which perform different switching operations.

Each switch within a multifunction control unit addresses computer logic, which determines the specific function of that switch and initiates the desired action when the control surface is activitated. Since the function of a particular switch changes, current status of the switch must be displayed. There are several ways in which this can be accomplished:

- o rear projecting legends onto pushbutton switches,
- o generating legends remotely and transmitting to switch face with fiber optics,
- o generating legends on an electronic display with switches located in the periphery,
- o generating legends on an electronic display and then activating the area which has been designated (touch, light pen, photo-sensitive detectors, etc.),
- o generating legends directly on the switch face.

3.2.2.4 Voice Actuated Controls - As modern aircraft become increasingly more sophisticated, additional responsibilities are created which add to an already burdensome pilot workload. The concept of voice actuated systems (VAS) is one potential solution to this problem. In fact, the applications can be extended in principle to incorporate "thought" commands, as discussed in Subsection 6.3.

The purpose of VAS is to permit more direct communication with the computer, thereby alleviating conventional workload and providing additional time to perform higher level tasks.

The particularly desirable features of VAS are: a reduction in manual control procedures (especially during critical flight phases), a reduction in eye-hand coordination problems, and a reduction in visual demands inside the cockpit. A representative application may be found in weapons delivery. During this mission phase, the pilot is concerned with the sequence of events necessary to properly arm and deliver weapons on a target, to maintain altitude and airspeed within acceptable limits, to perform required communications, and to remain alert for enemy threats. With VAS, it may be possible for the pilot to change radio channels and to arm and deliver weapons by simple voice commands. Hence, more time and attention can be given to target acquisition, lock-on, flight control and threat avoidance.

Voice data entry systems are already in use for a number of interactive command and control functions. However, these systems have a limited vocabulary and are speaker specific. Vocabularies typically consist of digits and a small set of control words and phrases.

3.2.2.5 Joint Tactical Information Distribution System (JTIDS) - JTIDS is a digital communication system for secure, real-time command and control of combat operations. JTIDS will interconnect the tactical defense elements of all services with surveillance/intellegence centers and with command and control centers in the theatre of operations. Precise time-of-arrival measurements, coupled with the transmission of emitter location, are used to generate a common grid coordinate system containing the location of all active net participants. The system uses Time Division Multiple Access (TDMA) to interconnect all users via one common channel for the distribution of information. Each authorized element is allocated a number of transmission time slots. When not transmitting, each element monitors the transmissions of all other elements and extracts the information as needed.

Although the specific benefits of JTIDS have not been documented, several generic benefits affect tactical missions. These are:

- o jam resistant communications,
- o intercept enhancement,
- o "Beyond Visual Range" threat identification,
- o supplementary threat warning,
- o relative nayivation,
- o blind NAV bombing capability.

JTIDS is a multiphased program which is scheduled to achieve full operational status by 1984.

3.2.2.6 Airborne Warning and Control System (AWACS) - AWACS will provide air surveillance for command, control and communication functions throughout the U.S. and overseas. Its radar will detect and track aircraft at any altitude over land and water.

3.2.2.7 Global Positioning Satellite (GPS) - GPS will provide precise, three-dimensional position and velocity information to aircraft, ships, and ground forces. The GPS development is currently in the validation phase, with early results indicating that the system can meet anticipated accuracy requirements. Full scale development should begin in 1982. Eventually, 24 satellites will be orbited for full global coverage by 1984.

4.0 MISSION REQUIREMENTS

General mission requirements were listed earlier (see Figure 3.4) for pre-flight, in-flight, and post-flight phases. From these requirements, representative mission profiles were illustrated for Close Air Support, Air Interdiction, and Counter Air missions (see Figures 3.5, 3.6, and 3.7, respectively).

Our intent in this section of the report is to describe the mission requirements in more detail. This is followed (in Section 5) by an examination of pilot information needs. After establishing tactical objectives and defining the corresponding information requirements, we present (in Section 6) time line analyses of the specific tasks which must be performed.

We have chosen a presentation format (adapted from Mills et al., 1978) which will facilitate comparison of the requirements for the principal TACAIR missions. The numbering scheme used to identify individual mission requirements is the same as that used in Figure 3.4. Notes are included when further clarification or differentiation is necessary. We should emphasize, again, that the mission requirements overlap in combat situations.

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1. Pre-Flight			
1.1 Mission Planning	1.1 All tasks related to safe and effective conduct of the mission. These include at a minimum: (a) Briefings: weather, intelligence, rules of engagement, targets, and weapon deliveries. (b) Computations: time, distance, headings, fuel, and ballistics. (c) Maps. (d) Enroute Procedures: formation, navigation, communication. (e) Air refueling procedures and call signs. (f) Alternate missions. (See Note 1)	1.1 Same as Close Air Support. (See Note 2)	1.1 Same as Close Air Support. (See Note 3)

NOTES:

(1) Close Air Support missions emphasize quick response and receive the highest priority when friendly forces are engaged with the enemy and in desperate need of all available resources. Therefore, if a mission is scrambled from an alert status or if aircraft are diverted from another mission, there may be little or no time for mission planning. In these cases, the aircrew must rely on experience, on-board systems, and in-flight communications.

(2) Since Air Interdiction missions are generally conducted against large, less mobile targets, there is frequently more time for detailed flight planning. With the exception of mobile targets, target location and description are usually known very accurately.

(3) Although Counter Air missions demand considerable pilot skills, they generally require less detailed mission planning than the air-to-ground missions. However, more in-flight decisions must be made.

FIGURE 4.1 PRE-FLIGHT MISSION REQUIREMENTS FOR CLOSE AIR SUPPORT, AIR INTERDICTION, AND COUNTER AIR.

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1.2 Pre-Flight	(a) Personal Equipment: all tasks associated with the inspection and donning of flight gear (e.g., g-suits, parachutes, helmets, etc.).	Same as CAS.	Same as CAS. (See Note 4)
	(b) Aircraft: assure aircraft is in physical condition for flight and that it is equipped properly for the proposed mission objectives. Check fuel or hydraulic leaks, weapon configurations, reservoirs, tires, panels, etc..		
	(c) The aircrew is responsible for checking the AFTO 781 to assure that the aircraft has been properly serviced and released for flight by maintenance. Open discrepancies (items not repaired) and their effect on the proposed mission are evaluated at this time. (See Note 4)		

NOTE:
(4) Most pre-flight tasks are performed in advance of an alert. Otherwise, these tasks are performed just prior to the mission. Alert status requires specified aircraft and aircrews and, therefore, reduces the resources available for other missions or duties.

FIGURE 4.2 PRE-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1.3 Start and System Checks	1.3 Check normal system operations. Verify equipment applicable to mission. Make go/no go decision depending on equipment status.	1.3 Same as CAS.	1.3 Same as CAS.
1.4 Taxi	1.4 (a) Receive clearance. (b) Taxi aircraft from parking area to arming area, exercising caution to avoid other aircraft and maintenance vehicles and equipment. (c) Aircraft must be taxied in appropriate formation, regardless of location on ramp. (See Note 5)	1.4 Same as CAS. (See Note 5)	1.4 Same as CAS. (See Note 5)

NOTE:
(5) Ramp congestion or damage, night operations, a new airfield with unfamiliar takeoff procedures, and other unusual circumstances can significantly confuse taxi operations. The results can vary from a delayed mission to damaged or even destroyed aircraft.

FIGURE 4.3 PRE-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
1.5 Arming	1.5 Aircraft weapons and munitions are armed and mechanically unsafed by ground crews. The aircrew is required to maintain hands off all switches and controls and, if possible, in such a position that they are visible to the ground crew. (See Note 6)	1.5 Same as CAS.	1.5 Same as CAS.
1.6 Takeoff	1.6 (a) Receive clearance. (b) Lineup checks (systems and configuration checks). (c) Takeoff Roll - One of most important phases of flight because of the criticality of major subsystem malfunctions. (d) With live munitions onboard, this phase of flight is further complicated by different handling characteristics, including rotation and lift off speeds and slower acceleration.	1.6 Same as CAS. (See Note 7)	1.6 Same as CAS except: (d) does not usually apply, since the munitions generally weigh much less and therefore have a lesser effect on the aircraft's performance.

NOTES:

(6) Arming is generally conducted in a clear area as close to the end of the runway as possible. No additional maintenance can be performed on the aircraft unless it is once again safed. Although arming is a relatively simple procedure, it ranks very high in importance. If done improperly, it can result in an ineffective mission or damage to and loss of the aircraft. In some aircraft, it is impossible for the aircrew to confirm that the ground crews have properly performed their tasks. There are no cockpit indications that "pins" have been pulled or that a weapon, such as a gun, is armed.

(7) If nuclear weapons are carried, then takeoff, abort and jettison procedures may change. Nuclear weapons will not be jettisoned from the aircraft, even during an emergency.

FIGURE 4.4 PRE-FLIGHT MISSION REQUIREMENTS (CONCLUDED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2. In-Flight			
2.1 Climb to Level Off	2.1 (a) Monitor systems and perform additional system checks. (b) Monitor formation. Formation considerations are involved throughout the remainder of the flight and vary depending on phase, weather, and enemy action. (The requirements related to leading a formation are so complex that it is impossible to briefly address them. They are, however, a primary consideration in multi-aircraft missions.) (c) Follow clearance instructions. (See Note 8)	2.1 Same as CAS except: formation considerations may not always be a factor. Some air interdictions are conducted by a single aircraft.	2.1 Same as CAS.
2.2 Cruise	2.2 (a) Monitor systems. (b) Review mission. (c) Follow clearance instructions.	2.2 Same as CAS. In addition: (a) Time spent in cruise may be much greater than for CAS or Counter Air. (b) Time of arrival considerations are more critical than for CAS or Counter Air.	2.2 Same as CAS.

NOTE:
(8) Formation procedures for a specific aircraft are very clearly defined and allow for little deviation.

FIGURE 4.5 IN-FLIGHT MISSION REQUIREMENTS FOR CLOSE AIR SUPPORT, AIR INTERDICTION, AND COUNTER AIR.

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.3 Loiter	2.3 Remain in a specified location awaiting further enemy activity or until additional instructions are received.	2.3 Not normally required.	2.3 Same as CAS.
2.4 Rendezvous and Air-to-Air Refueling (AAR)	(2.4 Optional. Otherwise same as Air Interdiction. AAR would only be required if there were extensive delays in getting to a target or if the airbase is at a greater distance from the target area than generally desired.) (See Note 9)	2.4 (a) Rendezvous consists of joining mission aircraft with tanker aircraft. This phase relies heavily on standard procedures and precise inflight timing and navigation. (b) This phase must be conducted in a "safe" area or the tankers must be provided cover against enemy aircraft. (See Note 10)	(2.4 Optional. Otherwise same as Air Interdiction. Would be used to extend loiter time awaiting engagements.)

NOTES:

(9) Both loiter and AAR extend mission time. This has several advantages, such as for decreasing the response time to get friendly air power over enemy targets. As long as adequate weapons are on-board an aircraft, it is advantageous to keep it airborne awaiting conflict. Limits to be considered are fatigue, exposure to risk, and the availability of support forces (such as tankers).

(10) AAR can also be directed from ground radar control facilities. This is a more efficient method which reduces aircrew task loading. However, it relies heavily on radar and communications and, therefore, is subject to jamming or deception.

FIGURE 4.6 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.5 Coordination	2.5	2.5	2.5
	(a) Aircrew receives general instructions and sufficient details to contact a specific ground or airborne forward air controller (FAC).	(a) Receive final clearance for primary mission or a change to a secondary mission. Recent information will be added, such as a weather update or the position of enemy fighters.	(a) Fighters will be directed to areas of suspected enemy activity.
	(b) FAC provides details of the targets, such as type, number, and location. Enemy defenses and other restrictions are communicated. Friendly troop positions are designated.	(b) Authenticate message if a change in mission is conveyed. This may also be required to confirm go-ahead on primary mission.	(b) Warnings will be transmitted when enemy aircraft are observed to be maneuvering for an attack on friendly fighters.
	(c) The FAC, in many cases, will act as the controller and give positive clearance to release ordnance. This is particularly true in cases where enemy and friendly forces are in very close contact.	(c) Additional information may be relayed in the "blind", such as fighter escort call signs, tanker location, and SAM warnings.	(c) SAM warnings will be issued.
	(d) The mission aircraft will normally hold clear of the target area until this information is completed. An exception is a permissive air environment.	(See Note 12)	
	(See Note 11)		

NOTES:

(11) The Tactical Air Control System (TACS) coordinates both preplanned and immediate CAS operations. This system provides hardware, command and control, and an approved interface with Army units for CAS and some shallow interdiction missions.

(12) Since many of the aircraft dedicated to this mission have a nuclear capability, the aircrews must be knowledgeable of all applicable directives and safety requirements.

FIGURE 4.7 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.6 Mission Rendezvous	2.6 Join-up at a specified position and time with other elements of the strike force. These may include fighter cover and screening forces, such as ECM or Chaff dispensing aircraft. Accurate detection and identification are important during this phase to avoid errors. Common radio frequencies facilitate this type of join-up. (See Note 13)	(2.6 Optional: Not normally required on deep interdiction missions. May be required on shallow interdiction missions, in which case the same as close air support.)	(2.6 Optional: (a) On many missions a counter air strike force operates independently. In this case, positive target identification is required prior to attack. (b) Join-up with other elements in the strike force may be required. Usually, the counter air forces are tasked to provide attack cover. This join-up could be with elements of either CAS or Air Interdiction missions and may require different tactics to maintain formation integrity.) (See Note 13)

NOTE:
(13) Elements joining together in a common strike force may be from different units or bases. They may not have been briefed together and, therefore, will rely on instructions provided through the chain of command. Rendezvous relies heavily on radar, UHF communications, and pre-briefed signals or codes.

FIGURE 4.8 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.7 Penetration	2.7 (a) Medium: This tactic will be used primarily when enemy forces have no ground defenses or only light arms fire. Also used when enemy air is not a threat or if fighter cover is provided. CAS aircraft will fly into the target area and descend to combat altitudes. Fighter cover would remain at higher altitudes. (b) Low: This tactic is employed when the CAS aircraft are operating in a heavily defended area. The formation would be split or staggered and would penetrate at very low altitudes using the terrain to mask its position. In the vicinity of the target area the aircraft would "pop up" to deliver the weapons and when the ordnance is expended, egress at low altitudes. This profile is considerably more demanding on the crew, since the low level route must be flown with great precision. The target area must be somewhat familiar or easily distinguished, since there is little time for search and identification.	2.7 (a) Low: For deep interdiction this is a preferred method. It uses terrain masking for concealment until the aircraft reach target area. This takes advantage of surprise and reduces exposure to enemy defenses. This mission requires sophisticated aircraft systems for night or adverse weather conditions, including terrain following radar (TFR) and very accurate navigation equipment. (b) Medium: This is considered an unattractive option because it provides almost every enemy defense system an opportunity to detect and fire at the aircraft. Advances in ECM and other self-defense mechanisms could make it viable option. (c) High: This option allows the aircraft to fly above most enemy threats. It requires relatively high speeds to reduce exposure to the few enemy aircraft capable of sustained high altitude operation.	(2.7 Optional: It is unlikely that counter air scrties would, by themselves, penetrate heavily defended areas to patrol for enemy fighters.)

FIGURE 4.9 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.8 Threat Warning	2.8 (a) Aircrew must be prepared well in advance of actual enemy air attacks, since CAS aircraft are usually slower and less maneuverable, especially when heavily loaded with ordnance. Threat information may come from on-board systems or be relayed from ground radar. (b) The location of ground-based enemy systems must be known, preferably in advance of mission. CAS aircraft are very vulnerable to such systems, particularly SAMs and heavy AAA. (c) The prescribed action to defeat the detected enemy threat should be inherent in a detection system. This can vary from maneuvering to the use of chaff, flares, or ECM systems.	2.8 Basically, the same requirements as for CAS aircraft. In general, air interdiction aircraft are sometimes more capable of evading enemy defensive systems. However, since they operate at a greater distance from friendly forces, they cannot always make use of ground-based alerts or cautions.	2.8 (a) SAMs and enemy fighters are the most significant threats to counter air aircraft. Since new counter air aircraft are extremely capable, they can avoid or defeat SAMs and enemy fighters if detected well enough in advance. (b) Some countermeasures are necessary to provide additional protection and to relieve self-defense task loading.

FIGURE 4.10 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.9 Detection (Determination that a potential target may exist. Sources may vary.)	2.9 (a) First phase of actual combat. Necessary information may have been provided prior to the mission. (b) This task can be accomplished by a ground-based or airborne FAC. The FAC will then advise the mission aircraft of the target positions. (c) In designated free fire zones, the flight leader may detect targets of opportunity without "detailed coordination" with ground forces. (d) CAS is concerned only with detecting enemy ground targets.	2.9 This task, because of the general target types, is usually completed well in advance of the mission. The target type and characteristics are briefed in the mission planning. (a) Air interdiction is concerned only with enemy ground targets.	2.9 Since enemy aircraft are the only targets considered, information related to their positions must be near real-time. Therefore, there is a much greater emphasis on aircraft detection systems.

FIGURE 4.11 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.10 Location (Potential target positioned within a designated reference system. The purpose is to locate the target with sufficient accuracy to support the remaining mission functions, i.e., identification, decision, execution, and assessment.)	2.10 (a) Location must be known very accurately, particularly in reference to friendly forces. This task can be initiated before flight, but usually must be completed in-flight since targets may have moved or may be camouflaged. (b) The aircrew must make final determination of the target location. (See Note 14)	2.10 Location must be known precisely. The tasking of this mission is so demanding that on-board systems must direct weapons as close to the target as possible.	2.10 Location for counter air targets is in terms of relative position. This information must be known for air-to-air tactics and for selection of weapons. Pre-mission planning is usually of limited value. In-flight updates are necessary to give counter air forces an overview of the air battle. (See Note 15)

NOTES:
(14) Future weapon concepts present options that may eliminate aircrew involvement in target location.

(15) The value of detailed mission planning is reduced because air targets can vary their locations over a relatively broad spectrum of altitudes.

FIGURE 4.12 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.11 Identification (Potential targets are classified to support decision making. This may require information from several sources or simple visual identification.)	2.11 The target must be clearly identified as enemy. If this cannot be done, the attack cannot continue. Visual confirmation is usually required. (See Note 16)	2.11 Identification is important to mission success, but to a lesser extent than for CAS. Since air interdiction attacks are conducted well behind enemy lines, errors are less likely to affect friendly forces. (See Note 17)	2.11 Identification in an air battle is extremely important, particularly when different formations and aircraft types are involved. Therefore, "beyond visual range" targets require other methods for classification as friend or foe. These include IFF and radar signature. Close-in combat is ideally suited for visual identification.

NOTES:

(16) In an all-weather CAS scenario, not only is it important to identify a target as a tank, but also as a friendly or enemy tank. This difference, of course, is substantial and the requirement further complicates an already difficult mission.

(17) This is not always true, since the "rules of engagement" (ROE) may require positive target identification. The goal in this regard is either to limit nonmilitary, collateral damage or to avoid acts that might precipitate alignment of other countries with the enemy.

FIGURE 4.13 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.12 Decision (Potential targets and available strike resources are assessed and a course of action is determined. This function is integrative in nature.)	2.12 The final decision regarding actual weapons release is made by the pilot. He makes this decision based on the information received up to and including the time of release. (In combat there is very real pressure to release the ordnance and egress from the target area.) (See Note 18)	2.12 Same as CAS. Additionally, the attack may be conducted against targets not visually identified. (See Note 18)	2.12 (a) Same as CAS except: In close combat, the decision is only "when to fire" since there is usually little doubt as to target identification. (b) Beyond visual range targets must be classified by other methods and, therefore, the confidence level of any decision is reduced. (See Note 18)
2.13 Execution (This is the function in which the chosen course of action is implemented. This action may be either defensive or offensive.)	2.13 Execution implies that the command be given to the release mechanism to free the weapon from the aircraft. (In advanced weapon systems, the weapon may require guidance until final impact.) Frequently, the actual time of release is computed automatically and, provided there is consent, the weapon is delivered. Execution presumes all other arming functions are completed.	2.13 Same as CAS.	2.13 Same as CAS.

NOTE:
(18) The decision-making process is not easy to explain. Training, ROEs, previous experience, and many other factors affect split-second decisions to release weapons.

FIGURE 4.14 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.14 Assessment (This is the function in which the impact of aerospace operations upon enemy forces and capabilities is appraised. The purpose of this function is to provide an objective evaluation of the degree to which current operations achieve assigned objectives.)	2.14 This task requires objective evaluation of resultant damage. The aircrew can contribute to the success of this task, however, conditions may reduce the aircrew's ability to observe or assess damage in the target area. Included are such limiting factors as smoke and dust, enemy activities, weather, etc. Therefore, this task is frequently performed by the FAC or during a reconnaissance flight. The importance of assessment is directly proportional to the priority of the target. Frequently, the pilot has no way to record his assessment and must rely on memory during debriefing. (See Note 19)	2.14 Same as CAS, except the FAC may not be in a position to evaluate the mission success.	2.14 In close combat, assessment may be immediately obvious or, on the other hand, impossible. The task is further complicated since later reconnaissance flights are of little value.

NOTE:
(19) Each combat mission has the potential of acquiring additional intelligence information.

FIGURE 4.15 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.15 Termination	2.15 At some point, the aircrew must terminate the engagement. This decision is based on the following variables. (a) Target status (b) Fuel status (c) Ordnance remaining (d) Other circumstances, such as mission recall, heavy enemy defenses, damaged aircraft, deteriorating weather, etc.	2.15 Same as CAS except: (a) Deep strike air interdiction missions terminate at weapons delivery. Additional attacks are not usually planned, however, more than one target may be fired upon. (b) Shallow interdiction missions may allow for multiple attacks on the same targets, in which case the same criteria as for CAS will apply.	2.15 Same as CAS. An additional consideration is that the aircrew must be able to disengage from the enemy fighters. Termination is not always as easily achieved as in air-to-ground missions.
2.16 Egress	2.16 Depart from target area. This task includes all evasive tactics required to avoid enemy defenses and to rejoin the other aircraft in formation. Weather and other visibility restrictions complicate the task. If returning from enemy territory, "safe-passage" procedures may be required.	2.16 Low: Depart from target area in the same manner as penetration (see 2.7a), usually along a different route. High: Same as penetration (see 2.7c), except that route and altitudes may vary.	2.16 Normally not required, unless escorting other aircraft or engaging in other operations over enemy territory. In these cases, altitudes are usually medium to high.

FIGURE 4.16 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.17 Cruise	2.17 Same as 2.2 except: More emphasis will be placed on system checks in order to detect damage or other problems. There will also be greater emphasis on in-flight planning, particularly if the weather is marginal or a complicated approach must be flown. Alternate or emergency plans are formulated depending on existing conditions. (See Note 20)	2.17 Same as CAS. (See Note 20)	2.17 Same as CAS. (See Note 20)
2.18 Air Refueling	2.18 Same as 2.4 except: This AAR is much more critical. If there are any errors in planning or in estimating fuel consumption, distances, or times, then all aircraft on the mission could be lost. If the mission is terminated too soon, then the effectiveness may be less than desired.	(2.18 Optional. Same as CAS.)	2.17 Same as CAS. May demand multiple AAR to meet station time and fuel requirements.

NOTE:
(20) The aircrew must have a variety of inputs on the status of friendly airfields. These include weather, navigation aids, approach procedures, etc. Much of this information decays with time and, therefore, is not useful if stored prior to flight.

FIGURE 4.17 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.19 Re-engage	(2.19 Optional: Additional attacks after AAR may be possible depending on fuel, ordnance, position, and aircraft systems.) (See Note 21)	2.19 Not required.	2.19 Frequently required, but dependent on fuel, ordnance, crew fatigue, and aircraft systems. (See Note 21)
2.20 Return to Base	2.20 Knowledge of field conditions and alternatives is needed. This task is also dependent on aircraft systems, fuel, distances to the airfield, and other operations which might affect landings. (See Note 22)	2.20 Same as CAS. If additional missions are flown from an alternate base, then consideration must be given to specialized flight planning aids. (See Note 22)	2.20 Same as CAS. (See Note 22)

NOTES:
(21) The ability to re-engage in combat after refueling is very desirable. While this will depend on remaining ordnance, it does eliminate the need for ground facilities and maintenance support.

(22) Since an aircraft may have to divert at the last minute, information updates are required through the final landing.

FIGURE 4.18 IN-FLIGHT MISSION REQUIREMENTS (CONTINUED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
2.21 Descent	2.21 Requires planning for a specified approach or in conjunction with enroute radar descent. The key element is to save as much fuel as possible by trading altitude for airspeed.	2.21 Same as CAS.	2.21 Same as CAS.
2.22 Approach (All elements of aircraft maneuvering required to align the aircraft with the runway.)	2.22 This task requires maneuvering via instruments or radar vectors to align the aircraft with the landing runway. It is also necessary to maintain separation from other aircraft operations.	2.22 Same as CAS.	2.22 Same as CAS.
2.23 Landing (Actions required to position aircraft safely on the runway.)	2.23 The final phase of flight requires precise manipulation of flight trajectory. It necessitates close adherence to commanded airspeeds, angles of attack, rates of descent, and flight path along the ground. Smooth control is emphasized.	2.23 Same as CAS.	2.23 Same as CAS.

FIGURE 4.19 IN-FLIGHT MISSION REQUIREMENTS (CONCLUDED).

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
3. Post-Flight			
3.1 De-Arm	3.1 Maintenance crews safe remaining weapons and/or ejector cartridges, and advise aircrew of safety status. If an aircraft cannot be "safed," it normally will be shut down in a safe area and will not be taxied with other aircraft. Other systems requiring de-arming are flare and chaff ejectors. Procedures and requirements differ for guns, rockets, missiles, bombs, etc.	3.1 Same as CAS.	3.1 Same as CAS.
3.2 Taxi	3.2 Same as 1.4.	3.2 Same as 1.4.	3.2 Same as 1.4.
3.3 System Checks	3.3 (a) Perform all system checks or self-tests required to evaluate the aircraft's condition for the next mission. These checks emphasize mission essential equipment. (b) For damaged equipment, diagnosis is required so that maintenance crews can identify the problem.	3.3 Same as CAS.	3.3 Same as CAS.

FIGURE 4.20 POST-FLIGHT MISSION REQUIREMENTS FOR CLOSE AIR SUPPORT, AIR INTERDICTION, AND COUNTER AIR.

PHASE	CLOSE AIR SUPPORT	AIR INTERDICTION	COUNTER AIR
3.4 Shutdown	3.4 Aircraft systems turned off and pilot exits aircraft. All personal equipment and debriefing aids are taken from the aircraft. Expended supplies are also removed.	3.4 Same as CAS.	3.4 Same as CAS.
3.5 Post-Flight	3.5 Aircrew examines aircraft for battle damage or other unusual conditions, such as lost panels, bird strikes, etc.	3.5 Same as CAS.	3.5 Same as CAS.
3.6 Debrief	3.6 Completion of all forms and documentation tasks. The key element is the ability to relay all useful information to maintenance, operations, intelligence and higher command units. Mission-related information includes damage assessment, location of enemy SAMs, troop concentrations, enemy tactics, etc.	3.6 Same as CAS.	3.6 Same as CAS.

FIGURE 4.21 POST-FLIGHT MISSION REQUIREMENTS (CONCLUDED).

5.0 INFORMATION NEEDS

It should be obvious, from even a cursory reading of the mission requirements, that a combat pilot must spend considerable time processing displayed information. In Section 3, we reviewed the various display units which will present visual information during the 1990s (see Figures 3.1 and 3.2). In this section, we are concerned with the specific types of information which must be displayed at different stages of each TACAIR mission. Therefore, we have provided comprehensive listings of information requirements. We believe that the mission and information requirements, coupled with the aircraft characteristics, determine the assignment and sequencing of pilot tasks.

The tabulations which appear in Figures 5.1 through 5.12 (adapted from Mills et al., 1978) indicate whether the displayed data are: required (1), frequently required (2), or merely of additional value (3) at a certain stage of the mission. Thus, an entry of "2" or "3" signifies that this particular information is less essential than information assigned a weight of "1."

	Pre-Flight						In-Flight																							Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	(2.19 Reengage)	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Administrative																																			
Formation Call Signs	1	1	2	1	3	1	2	2	2	1	1	1	2	2	2	2	2	2	1	2	2	2	2	1	2	2	2	2	2	2	2	2	2		1
Flight Position	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2				
Aircraft Assignment	1	1	1																																
Parking Spot	1	1	1	2	3																														
Spare Procedures	1	2	2	2	2																														
Aircraft Configuration	1	1	1	1	1	1	2	2	2	1	2	2	1	2	2	2	2	1	1	1	1	1	2	1	1	2	2	1	1	1	1				1
Frequencies	1		1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1			
IFF/SIF Procedures	1		3	2		1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	1	1	1	1	1	1	1	1						
Weather	1	2	2	2	2	1	2	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1						
Regulations	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Airfield Status																																			
Airfield Description	1	3	3	1	1	2																					2	2	1	1	1	1	2	1	
Landing Runway	1	2	2	1	1	1																				2	2	1	1						
Runway Length	1	3	3	2	2	1																					2	1	1						
Barriers	1			2	2	1																					2	1	1						
Approaches	1			2	2	2																					1	1	1						
Missed Approach Instructions																											3	1							
Airfield Elevation	1		1	2		1																				2	1	1	1			1			
Decision Height																										3	2	1							
Parking Area	1	1		1	1																								3	1	1	1	1	1	
Taxi Routes	1	2	2	1	1	3																							1	1	1	1	1	1	
Arming Area	1			1	1																								2	1	2				
Dearming Area	1			1	1	3																							2	1	2				
Alternate Airfield	1					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Time																																			
Briefing Time	1																																		
Station Time	1	1																																	
Start Engine Time	1	1	1																																
Flight Check In Time	1	1	1	1																															
Taxi Time	1	1	1	1																															
Takeoff Time	1	1	1	1	1	1																													
Air Refueling Contact Time	1	2	2	2	2	2			2	1													2	1											
Time on Target	1	2	2	2	2	2	2	2	2	2	1	1	1	2	1	1	1	1	1																1
Time to Climb	1					2	1															2													
Time to Go	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Control Times	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Landing Time	2																						2				2	2	2						
Rendezvous Time	1									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1									
Enroute Times	1						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Time of Day	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Caution and Warning Systems																																			
Master Caution	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Configuration Warnings		1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1						1
Operating Limitation Warning	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Primary Systems Fail		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Fuel Low			2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2		
Oxygen Low		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	2			
Environmental Control System Warning			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Autopilot Disengaged							2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2						
Avionics Malfunctions	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1	3	3	1	2	3	1
Altitude Low						1	2	2	2	3	2	2	1	1	1	1	1	1	1	1	1	1	2	3	1	2	1	1	1						
Airspeed Low						1	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1						

FIGURE 5.1 INFORMATION REQUIREMENTS FOR CLOSE AIR SUPPORT.

	PreFlight						In-Flight																							Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	(2.19 Reengage)	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Miscellaneous																																			
Fuel Off Loading	1									1														1											1
Gross Weight	1		1	1		1																						1	1						2
Autopilot Submodes			1				2	2	2	3	2	2	1	1	1	1	1	1	1	1	1	2	2	3	1	2	2	1	1						
Aircraft Lighting		1	1	1	1	1	2						1									1		1	1			1	1	1	1	1		1	1
g																																			2
Communications																																			
Controlling Agency	1		2	1	1	1	2	2	2	1	1	1	2	2	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1				
Aircraft Call Sign	1		1	1	2	2	2	2	2	1	1	1	2	1	2	2	2	2	2	2	2	2	2	1	1	2	2	2	1	2	1	2	2		
Authentication	1									1	1	1							1					1	1	1									
IFF/SIF	1		1	2		1	1	1	1	1	1	1	2									1	1	1	1	1	1	1	1						
Clearances	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Secure Communication										1	1	1	1	1	1	1	1	1	1	1	1			1											
Frequencies	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2		
Intercom (If Required)																														2	2	2	2		
Navigation Aids Identifiers								2															2												
Mission Reports								2	2	2	1	1	2	2	2	2	2	2	2	1	2	1	2	1	1	2	2	2	2						1
Flight Aids																																			
Normal Checklists	1	1	1	1	1	1	2	3	3	1	3	3	3	3	3	3	3	1	1	3	3	3	3	1	3	3	2	2	1	1	2	1	1	1	
Emergency Checklists	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
Procedures	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Approach Aids	1					1	2																			2	1	1	1						
Emergency Airfields	1						3	2																											
Personal Techniques	1		2												2	2	2		2	2	2											2			2
Navigation																																			
Course	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1
Heading			2	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		2	1			2
Flight Path						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Pitch Steering			2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Bank Steering			2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Glide Slope			3	2		3																					2	1	1			2			
Localizer			3	2		3																					2	1	1	1		2			
Distance to Destination	1			2		2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Bearing to Destination				2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Destination Selected	1		2	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Marker Beacon																												1	1			2			
Present Position	1		1	2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			
Destination Offsets	1			2			1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1			2			
Magnetic Variation	1		1	3																												2			
Coordinates			1	2																												2			
Navigation Point	1		1	2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			1
Planned Route of Flight	1		1	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			1
Holding Patterns	2								1	1		1														2	2	2	2						
Minimum Descent Altitude																										3	2	1	1						
Missed Approach Point																										3	2	1	1						

FIGURE 5.2 INFORMATION REQUIREMENTS FOR CLOSE AIR SUPPORT (CONTINUED).

	Pre-Flight						In-Flight																						Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	(2.19 Reengage)	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Altitude																																			
Altitude Above Ground Level (AGL)	3						2	3	1	3	2	2	1	1	1	1	1	1	1	1	1	1	2	3	1	3	1	1	1						
Altitude Above Mean Sea Level	2		1			2	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1			1			
Altimeter Setting			1				1	1	1																	1	1	1	1						
Command Altitude			1			2	1	1	1	1		1	1	1	2	2	2	2	1	2	2	1	1	1	2	1	1	1	1						
Target Elevation	1													1	1	1	1	1	1	1	2														
Minimum Enroute Safe Altitude							2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Terrain Altitude	1		1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			
Terrain Clearance							1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1						
Velocity																																			
Vertical Velocity						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Rotation Speed						1																													
Takeoff Speed						1																													
Check Speeds						1																													
Climb Speed (Normal)						2	1																												
Climb Speed (Maximum Performance)						3	1																												
Maximum Range Cruise								1														1	1			2	2								
Maximum Endurance									1																	2	2								
Maximum Range Descent																										2	2								
Approach Speed						3																					2	1	1						
Landing Speed						3																						2	1						
Maximum Safe Speed								3					2						2				3												
Minimum Controllable Speed						1	2		2										2								2	1	1						
Limitations	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Corner Speed																						2													
True Airspeed	3					3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
Angle of Attack (AOA)																												3	3						
Ground Speed	1			2		3	3	2	3		3	3	2	3	3	3	3	3	2	3	3	2	3		3	2	2	2	2		2				
Wind Velocity and Direction	1					1		2											2				3			2	2	2	1						
Turn Rate																											2	2	2						
Best Rate of Climb						2	2															3													
Best Angle of Climb						2	2																			2									
Mach Number	3						3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
Selected Speed						2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2						
Emergency Airspeeds	3					2	2	2		1								2						1			2	2	2						
Weapons Release Speeds	2														2	2	2	1	1	1	2														
IAS																																			
Systems																																			
Fuel Flow	1		2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3			
Fuel Remaining	1		1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	2	2	2	1		2
Fuel Required to Destination	1	1	1	3			3	1	1	1	2	1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	3	3	3	3	3	
Fuel Management		2	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		2
Hydraulic		2	1				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	1	3	3	3	3	3	3	3	3	2	2	2
Electrical			1				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	2	2	2
Oxygen		2	1				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	2	2	2
Engine			1			1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	2	2	2

FIGURE 5.3 INFORMATION REQUIREMENTS FOR CLOSE AIR SUPPORT (CONTINUED).

	PreFlight						In-Flight																							Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	(2.19 Reengage)	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Penetration Aids																																			
AI Warning			1			2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3						
SAM Warning			1			2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3						
Threat Avoidance			1			2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3						
Disposables Status	1	1	1	2	1	3	3	3	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3			2			2		1
ECM Status	1	1	1	2			3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3						2		1
ECM Tactics	1	1	1				3	3	2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3						2		1
Mutual Support	1						3	3	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2								1
Special Threat	1		1				3	3	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2								1
Weapons Information																																			
Ballistics	1		1																																
Weapons Envelope	1												1	1	1	1	1	1	1	2	2	2	2	3	1	3									1
Weapons Ready					1								1	1	1	1	1	1	1	3	3	2	2	2	1	2									1
Weapons Release					1								1	1	1	1	1	1	1	1	2	2	2	2	1	2									1
Weapons Remaining		1	1		1						1		1	1	1	1	1	1	1	1	1	2	2	2	1	2	1	1	1	1					1
Weapons Impact													2	2	2	2	2	2	1	1	1	2	2	2	1	2									1
Weapon Selected		1	1								1		1	1	1	1	1	1	1	1	1	2	2	2	1	2									1
Bomb Fall Time/Impact Point	1										1		1	1	1	1	1	1	1	1	1	2	2	2	1	2									1
Weapons Options Selected	1	1	1		1								1	1	1	1	1	1	1	1	3	2	2	2	1	2	1	1	1	1					1
Weapons Delivery Selected	1	1	1		1								1	1	1	1	1	1	1	1	3	2	2	2	1	2	1	1	1	1					1
Air to Air Target																																			
Range										1		1		1	1	1	1	1	1	1	1			1											
Bearing										1		1		1										1											
Overtake										1		1		1										1											
Altitude Differential										1		1		1										1											
Target Turn Rate	3									2		2		2										2											
Target Attitude										2		2		2										2											
Identification										1		1		1										1											
Target Altitude										1		1		1										1											
In Range										2		1		1										2											
Aim Point										3		1												3											
Breakaway										1		1		1										1											
Air to Ground Target Acquisition																																			
Target Range														1	1	1	1	1	1	1	1				1	1			1						1
Target Bearing														1	1	1	1	1	1	1	1				1	1			1						1
Positive Target ID														1	1	1	1	1	1	1	1				1	1			2						1
Aim Point																		2	1	1	2				1	3			1						1
Break Away (Pullup)													1	1	1	1	1	1	1	1	1	1			1		1		1						1

Legend:
1 Required information
2 Frequently required information
3 Additional value
( ) Optional phases

FIGURE 5.4 INFORMATION REQUIREMENTS FOR CLOSE AIR SUPPORT (CONCLUDED).

Pre-Flight

	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff
Administrative						
Formation Call Signs	1		2	2	2	1
Flight Position	1		2	1	1	1
Aircraft Assignment	1	1	1			
Parking Spot	1	1	1	2	3	
Spare Procedures	1	2	2	2	2	
Aircraft Configuration	1	1	1	1	1	1
Frequencies	1		2	1	2	1
IFF/SIF Procedures	1		2	2		1
Weather	1	2	2	2	2	1
Regulations	1	1	1	1	1	1
Airfield Status						
Airfield Description	1	1	2	1	1	1
Landing Runway	2			1	1	1
Runway Length	1			2	2	1
Barriers	1			2	2	1
Approaches	1			2	2	2
Missed Approach Instructions	.					
Airfield Elevation	1		1	2		1
Decision Height						
Parking Area	1	1		1	1	
Taxi Routes	1	1	1	1	1	
Arming Area	1			1	1	
Dearming Area	1			1	1	
Alternate Airfield	1					2
Time						
Briefing Time	1					
Station Time	1	1				
Start Engine Time	1	1	1			
Flight Check In Time	1	1	1	1		
Taxi Time						
Takeoff Time	1	1	1	1	1	1
Air Refueling Contact Time	1	2	2	2	2	2
Time on Target	1	2	2	2	2	2
Time to Climb	1					2
Time to Go	1	1	1	1	1	1
Control Times	1		1	1	1	1
Landing Time	1					
Rendezvous Time	1					2
Enroute Times	1	1	1	1	1	1
Time of Day	1	1	1	1	1	1
Caution and Warning Systems						
Master Caution			1	1	1	1
Configuration Warnings	1	1	1	1	1	1
Operating Limitation Warning	1	1	1	1	1	1
Primary Systems Fail			1	1	1	1
Fuel Low			1	1	1	1
Oxygen Low			1	1	1	1
Environmental Control System Warning			1	1	1	1
Autopilot Disengaged			2	2	2	2
Avionics Malfunctions			1	1	1	1
Altitude Low						2
Airspeed Low						2

In-Flight

	2.1 Climb to Level Off	2.2 Cruise	2.4 Rendezvous and AAR	(2.6 Mission Rendezvous)	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	(2.18 Rendezvous and AAR)	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing
Administrative																				
Formation Call Signs	2	2	1	1	2	1							2	2	2	1	2	2	2	1
Flight Position	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aircraft Assignment																				
Parking Spot																				2
Spare Procedures																				
Aircraft Configuration	2	2	2	2	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Frequencies	1	2	1	1	2	1				2	2	2	2	2	2	1	1	1	1	1
IFF/SIF Procedures	1	2	1	1	1									1	2	1	1	1	1	2
Weather	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1
Regulations	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Airfield Status																				
Airfield Description																		2	2	1
Landing Runway																	2	2	1	1
Runway Length																		2	1	1
Barriers																		2	1	1
Approaches																	2	1	1	1
Missed Approach Instructions																		2	1	1
Airfield Elevation																		2	1	1
Decision Height																		2	1	1
Parking Area																				2
Taxi Routes																				1
Arming Area																				2
Dearming Area																				2
Alternate Airfield	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2
Time																				
Briefing Time																				
Station Time																				
Start Engine Time																				
Flight Check In Time																				
Taxi Time																				
Takeoff Time																				
Air Refueling Contact Time	2	2	1										2	2	2	1				
Time on Target	2	2	2	1	1	2	2	2	2	1	1	1	1	1						
Time to Climb	2													2						
Time to Go	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Control Times	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Landing Time															2		2	2	2	2
Rendezvous Time	2	2	1	1	2								2	2	2	1				
Enroute Times	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Time of Day	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Caution and Warning Systems																				
Master Caution	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Configuration Warnings	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Operating Limitation Warning	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Primary Systems Fail	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fuel Low	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Oxygen Low	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Environmental Control System Warning	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Autopilot Disengaged	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Avionics Malfunctions	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Altitude Low	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Airspeed Low	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Post-Flight

	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Administrative						
Formation Call Signs	2	2	2	2		1
Flight Position	1	2				
Aircraft Assignment			1	1	1	1
Parking Spot	1	1	1	1	1	1
Spare Procedures						
Aircraft Configuration	1	1	2		2	1
Frequencies	2	1	2			
IFF/SIF Procedures						
Weather						
Regulations	1	1	1	1	1	1
Airfield Status						
Airfield Description	1	1	1	2	1	
Landing Runway	1	1				
Runway Length						
Barriers						
Approaches						
Missed Approach Instructions						
Airfield Elevation			1			
Decision Height						
Parking Area	1	1	1	1	1	
Taxi Routes	1	1	1	1	1	
Arming Area	1	2				
Dearming Area	1	2				
Alternate Airfield						
Time						
Briefing Time						
Station Time						
Start Engine Time						
Flight Check In Time						
Taxi Time						
Takeoff Time						1
Air Refueling Contact Time						1
Time on Target						1
Time to Climb						
Time to Go						
Control Times						
Landing Time						
Rendezvous Time						
Enroute Times	1	1				1
Time of Day	1	1	1	1	1	1
Caution and Warning Systems						
Master Caution	1	1	1	1		
Configuration Warnings	1					1
Operating Limitation Warning	1	1	1	1		1
Primary Systems Fail	1	1	1	1		1
Fuel Low	2	2	2	2		
Oxygen Low	3	3	2			1
Environmental Control System Warning	1	1	1	1		1
Autopilot Disengaged						
Avionics Malfunctions	3	3	1			1
Altitude Low			1			
Airspeed Low			1			

FIGURE 5.5 INFORMATION REQUIREMENTS FOR AIR INTERDICTION.

	PreFlight						In-Flight																				Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.4 Rendezvous and AAR	(2.6 Mission Rendezvous)	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	(2.18 Rendezvous and AAR)	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Miscellaneous																																
Fuel Off Loading	1								1													1										1
Gross Weight	1		1	1																				1	1	1						2
Autopilot Submodes			2			2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			
Aircraft Lighting			1	1																												2
9																																2
Communications																																
Controlling Agency	1		1	1	2	1	1	1	1	1	2	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	2			
Aircraft Call Sign	1		1	1	2	1	2	2	1	1	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2		1
Authentication	1		2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3			2
IFF/SIF	1		2	3	3	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Clearances	1		1	1	2	1	1	2	1	1	2	2	2	2	2	1	1	2	2	2	2	1	2	2	2	1	2	2	2			2
Secure Communication			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Frequencies	1		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
Intercom (If Required)			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
Navigation Aids Identifiers	1		2	2		2	2	2	2	2											2	2	2	2	2	2						
Mission Reports	1		2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		1
Flight Aids																																
Normal Checklists	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Emergency Checklists	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Procedures	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Approach Aids	1		2	2	3	2	3																3	2	1	1						
Emergency Airfields	1		3	3		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Personal Techniques	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Navigation																																
Course	1		2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1
Heading			1	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		2	1			2
Flight Path			1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			2
Pitch Steering			1			1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Bank Steering			1			1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Glide Slope			1			3																	2	1	1	1			2			
Localizer			1			3																	2	1	1	1			2			
Distance to Destination	1		1			2	2	2	1	1	2	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1			2			
Bearing to Destination	1		1			1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1			2			
Destination Selected	1		1			1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1			2			
Marker Beacon																								2	1	1			2			
Present Position	1		1	2			2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			
Destination Offsets	1		1				1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	2	2					2			
Magnetic Variation	1		1																										2			
Coordinates	1		1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			1
Navigation Point	1		1			1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1			1			1
Planned Route of Flight	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2					1			1
Holding Patterns	2								1	1												1	2	2	2	2						
Minimum Descent Altitude	3																						3	2	1	1						
Missed Approach Point	3																						3	2	1	1						

FIGURE 5.6 INFORMATION REQUIREMENTS FOR AIR INTERDICTION (CONTINUED).

	PreFlight						In-Flight																							Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise		2.4 Rendezvous and AAR		(2.6 Mission Rendezvous)	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	(2.18 Rendezvous and AAR)		2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Altitude																																			
Altitude Above Ground Level (AGL)	3						2	3		3		2	1	1	1	1	1	1	1	1	1	1	2	3		3	1	1	1						
Altitude Above Mean Sea Level	2		1			2	1	1		1		1	1	1	1	1	1	1	2	1	1	1	1	1		1	1	1	1			1			
Altimeter Setting			1				1	1																		1	1	1	1						
Command Altitude			1			2	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1						
Target Elevation	1													1	1	1	1	1	1	1	2														
Minimum Enroute Safe Altitude								1		1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1						
Terrain Altitude	1		1				1	1		1		1	1	1	1	1	1	1	1	1	1	1	1				1	1	1			1			
Terrain Clearance							1	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		2	1	1	1						
Velocity																																			
Vertical Velocity						1	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1						
Rotation Speed						1																													
Takeoff Speed						1																													
Check Speeds						1																													
Climb Speed (Normal)						2	1															2													
Climb Speed (Maximum Performance)						3	3															2													
Maximum Range Cruise								2																		2	2								
Maximum Endurance								3																		2	2								
Maximum Range Descent																										2	2								
Approach Speed						3																					2	1	1						
Landing Speed						3																						2	1						
Maximum Safe Speed							2	2					3	3	3	3	3	3	3	3	3	2	3												
Minimum Controllable Speed						1	2	2					3	3				3	3	3	3	3				3	2	1	1						
Limitations	1	1	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
Corner Speed																					2	2													
True Airspeed	3					3	3	3		3			3	3	3	3	3	3	3	3	3	3	3	3											
Angle of Attack (AOA)																												3	3						
Ground Speed	2				3		2	2		3			2	2	2	2	2	2	2	2	2	2	2	3		2	3	3	3	2					
Wind Velocity and Direction	1			2		1	2	2		3									2				3			2	2	1	1						
Turn Rate																											2	2	2						
Best Rate of Climb						2	2															3													
Best Angle of Climb						2	2																												
Mach Number	3						3	3		3		3	3	3	3	3	3	3	3	3	3	3	3	3		3	3	3	3						
Selected Speed						2	1	1		1		1	2	2	2	2	2	1	1	1	1	1	2	1		2	2	1	1						
Emergency Airspeeds	3					2	2	2		1														1		2	2	2	2						
Weapons Release Speeds	2														2	2	2	2	1	2	2														
IAS																																			
Systems																																			
Fuel Flow	1		1	2	2	2	3	3		3		3	3	3	3	3	3	3	3	3	3	2	3	3		3	3	3	3	3	3	3	1		
Fuel Remaining			1	2	2	2	2	2		1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	2	2	2	1		1
Fuel Required to Destination	1		1	2	2	2	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1						
Fuel Management	3	2	1	2	2	1	3	3		1		3	3	3	3	3	3	3	3	3	3	2	3	1		3	3	2	2	3	3	3	3		2
Hydraulic		1	1	2	2	2	3	3		3		3	3	3	3	3	3	3	3	3	3	2	3	3		3	3	3	3	3	3	3	2	2	2
Electrical		2	1	2	2	2	3	3		3		3	3	3	3	3	3	3	3	3	3	2	3	3		3	3	3	3	3	3	3	2	2	2
Oxygen		2	1	2	2	2	3	3		3		3	3	3	3	3	3	3	3	3	3	2	3	3		3	3	3	3	3	3	3	2	2	2
Engine			1	2	2	1	3	3		3		3	3	3	3	3	3	3	3	3	3	2	3	3		3	3	3	3	3	3	3	2	2	2

FIGURE 5.7 INFORMATION REQUIREMENTS FOR AIR INTERDICTION (CONTINUED).

	Pre-Flight						In-Flight																						Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	//////	2.4 Rendezvous and AAR	//////	(2.6 Mission Rendezvous)	2.7 Penetration	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	(2.18 Rendezvous and AAR)	//////	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Penetration Aids																																			
AI Warning	1		1				2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		3									
SAM Warning	1		1				2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		3									
Threat Avoidance	1		1				2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		3									
Disposables Status		1	1	2	1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		2	1			2	2			2	1
ECM Status		1	1	2	1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		2	1								1
ECM Tactics	1						2	2		2		2	1	1	1	1	1	1	1	1	1	1	2	2		2									1
Mutual Support	1						2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		3									1
Special Threat	1						2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		3									1
Weapons Information																																			
Ballistics	1		1																																
Weapons Envelope	1		1				2	2		3		1	1	1	1	1	1	1	1	1	1	1	2	3											1
Weapons Ready		1	1	2	1	2	2	2		1		1	1	1	1	1	1	1	1	1	1	1	2	1		2	1	1	1						1
Weapons Release		1	1		1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		2	1	1	1						1
Weapons Remaining	1	1	1	2	1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	2		2	1	1	1						1
Weapons Impact												1	1	1	1	1	1	1	1	1	1	1													1
Weapon Selected	1		1		1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	3		3									1
Bomb Fall Time/Impact Point			1				2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	3		3									1
Weapons Options Selected			1	2	1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	3		3	1	1	1						1
Weapons Delivery Selected			1		1	2	2	2		2		1	1	1	1	1	1	1	1	1	1	1	2	3		3	1	1	1						1
Air to Air Target																																			
Range										1		1		1										1											
Bearing										1		1		1										1											
Overtake										1		1		1										1											
Altitude Differential										1		1		1										1											
Target Turn Rate										2		2		1										2											
Target Attitude										2		2		2										2											
Identification										1		1		1										1											
Target Altitude										1		1		1										1											
In Range										2		1		1										2											
Aim Point										3		1												3											
Breakaway										1		1		1										1											
Air to Ground Target Acquisition																																			
Target Range															1	1	1	1	1	1	1					1			1						1
Target Bearing															1	1	1	1	1	1	1					1			1						1
Positive Target ID															1	1	1	1	1	1	1					1			2						1
Aim Point																		2	1	1	2					3			1						1
Break Away (Pullup)													1	1	1	1	1	1	1	1	1	1					1		1						1

Legend: 1 Required information; 2 Frequently required information; 3 Additional value; ( ) Optional phases; ///// Not applicable to mission

FIGURE 5.8 INFORMATION REQUIREMENTS FOR AIR INTERDICTION (CONCLUDED).

	PreFlight						In-Flight																							Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	(2.7 Penetration)	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	2.19 Reengage	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Administrative																																			
Formation Call Signs	1		2	2	2	2	2	2	2	1	1	1	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2		1
Flight Position	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2				
Aircraft Assignment	1	1	1			2																								2		1	1	1	1
Parking Spot	1	1	1	2	3																									1	1	1	1	1	1
Spare Procedures	1	2	2	2	2																														
Aircraft Configuration	1	1	1	1	1	1	2	2	2	1	1	1	2	1	1	1	1	1	1	1	1	2	2	1	1	2	2	1	1	1	1	1			1
Frequencies	1		1	1	1	1	2	2	2	1	1	1	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2			
IFF/SIF Procedures	1		2	2	2	1	2	2	2	1	1	1	2	2	2	2	2	2	2	2	2	1	2	1	2	2	2	2	2						
Weather	1	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1						
Regulations	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Airfield Status																																			
Airfield Description	1	1	1	1	1	2	2																				2	2	1	1	1	1	2	1	
Landing Runway	1			1	1	1	2																			2	2	1	1						
Runway Length	1			2	2	1	2																				2	1	1						
Barriers	1			2	2	1	2																				2	1	1						
Approaches	1			2	2	2	2																				2	1	1						
Missed Approach Instructions																											2	1	1						
Airfield Elevation	1		1	2		1	2																				2	1	1			1			
Decision Height						2	2																				2	1	1						
Parking Area	1	1	2	1	1	2																							2	1	1	1	1	1	
Taxi Routes	1	1	2	1	1																								1	1	1	1	1	1	
Arming Area	1	2	2	1	1	2																							2	1	2				
Dearming Area	1	2	2	1	1	2																							2	1	2				
Alternate Airfield	1					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Time																																			
Briefing Time	1																																		
Station Time	1	1																																	
Start Engine Time	1	1	1																																
Flight Check In Time	1	1	1	1																															
Taxi Time	1	1	1	1																															
Takeoff Time	1	1	1	1	1	1																													
Air Refueling Contact Time	1	2	2	2	2	2			2	1													2	1											
Time on Target	1	2	2	2	2	2						1	1	1	1	1	1	1	1	1	1														1
Time to Climb	1					2	1															1													
Time to Go	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Control Times	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Landing Time	1																						2				2	2	2						
Rendezvous Time	1		2	2	2	2				1	1	1												1											
Enroute Times	1		2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Time of Day	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Caution and Warning Systems																																			
Master Caution			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Configuration Warnings	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1
Operating Limitation Warning	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Primary Systems Fail		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Fuel Low			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2		
Oxygen Low		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2			
Environmental Control System Warning			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Autopilot Disengaged			2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Avionics Malfunctions			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1			
Altitude Low			1			1	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1			1			
Airspeed Low			1			1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1			1			

FIGURE 5.9 INFORMATION REQUIREMENTS FOR COUNTER AIR.

	PreFlight						In-Flight																							Post Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	(2.7 Penetration)	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	2.19 Reengage	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Miscellaneous																																			
Fuel Off Loading	1									1														1											1
Gross Weight	1		1			1																					2	1	1						1
Autopilot Submodes			1			2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			
Aircraft Lighting			1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2
g																																			1
Communications																																			
Controlling Agency	1		1	1	1	1	2	2	2	1	1	1	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1	2	2	2			
Aircraft Call Sign	1		2	2	2	2	2	2	2	1	1	1	2	1	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2			
Authentication	1		2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	2	2						
IFF/SIF	1		1			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			1			
Clearances	1		2	2	2	1	2	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1						
Secure Communication			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Frequencies	1		2	2	2	2	2	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2						
Intercom (If Required)			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Navigation Aids Identifiers			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
Mission Reports	1		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						1
Flight Aids																																			
Normal Checklists	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Emergency Checklists	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Procedures	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Approach Aids	1					2	2																				2	1	1						
Emergency Airfields	1					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Personal Techniques	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Navigation																																			
Course	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1
Heading			1	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1			2
Flight Path			1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			2
Pitch Steering			1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Bank Steering			1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Glide Slope			1																								1	1	1			2			
Localizer			1																								1	1	1			2			
Distance to Destination	1		1			2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3			
Bearing to Destination	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1			
Destination Selected	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Marker Beacon			1																								1	1	1			2			
Present Position	1		1	2	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1			
Destination Offsets	1		1			1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
Magnetic Variation	1		1																													2			
Coordinates	1		1			2	3	3	3	3	3	3	3	1	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3			1
Navigation Point	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			
Planned Route of Flight	1		1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			2			1
Holding Patterns	2																									2	2	2	2						
Minimum Descent Altitude	2					2	2																			3	2	1	1						
Missed Approach Point	2					2	2																			3	2	1	1						

FIGURE 5.10 INFORMATION REQUIREMENTS FOR COUNTER AIR (CONTINUED).

	PreFlight						In-Flight																							Post Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	(2.7 Penetration)	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	2.19 Reengage	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Altitude																																			
Altitude Above Ground Level (AGL)	3						2	3	2	3	2	2	2	1	2	2	2	2	1	2	2	1	2	3	1	3	1	1	1						
Altitude Above Mean Sea Level	1		1			2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			
Altimeter Setting	1		1			1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1						
Command Altitude						2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Target Elevation	3							2	2	2	2	2	2	2	1	1	1	1	1	1	1	2	2	2	1	2									1
Minimum Enroute Safe Altitude	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Terrain Altitude	1		1			1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1			1			
Terrain Clearance	1		1			1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1						
Velocity																																			
Vertical Velocity						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Rotation Speed						1																													
Takeoff Speed	1					1																													
Check Speeds	1					1																													
Climb Speed (Normal)	1					1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3						
Climb Speed (Maximum Performance)	1					1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3						
Maximum Range Cruise	1							2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Maximum Endurance	1							2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Maximum Range Descent	1							2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Approach Speed	1					3																					2	1	1						
Landing Speed	1					3	2																				2	1	1						
Maximum Safe Speed	1					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2								
Minimum Controllable Speed	1					2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1						
Limitations	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						1
Corner Speed	1					[illegible]	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2									
True Airspeed						3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
Angle of Attack (AOA)																		3										3	3						
Ground Speed				1			1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2				
Wind Velocity and Direction	1			2		1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1						
Turn Rate	1						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Best Rate of Climb	1					1	1	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3						
Best Angle of Climb	1					1	1	3	3	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3						
Mach Number							3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3						
Selected Speed						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Emergency Airspeeds	1					1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2						
Weapons Release Speeds	1						2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	2	2	2	2	2									1
IAS						1	2	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	1	1						
Systems																																			
Fuel Flow	1		1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1		
Fuel Remaining	1		1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	2	2		1
Fuel Required to Destination	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	2	2		
Fuel Management	1		1	2	2	2	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	2	2		2
Hydraulic		2	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	2	2
Electrical		2	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	2	2
Oxygen		2	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2
Engine		2	1	2	2	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1	2	2

FIGURE 5.11 INFORMATION REQUIREMENTS FOR COUNTER AIR (CONTINUED).

	PreFlight						In-Flight																							Post-Flight					
	1.1 Mission Planning	1.2 Preflight	1.3 Start and System Checks	1.4 Taxi	1.5 Arming	1.6 Takeoff	2.1 Climb to Level Off	2.2 Cruise	2.3 Loiter	(2.4 Rendezvous and AAR)	2.5 Coordination	2.6 Mission Rendezvous	(2.7 Penetration)	2.8 Threat Warning	2.9 Detection	2.10 Location	2.11 Identification	2.12 Decision	2.13 Execution	2.14 Assessment	2.15 Termination	2.16 Egress	2.17 Cruise	2.18 Rendezvous and AAR	2.19 Reengage	2.20 Return to Base	2.21 Descent	2.22 Approach	2.23 Landing	3.1 De-Arm	3.2 Taxi	3.3 System Checks	3.4 Shutdown	3.5 Post-Flight	3.6 Debrief
Penetration Aids																																			
AI Warning	1		1				3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3			1			1
SAM Warning	1		1				3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3			1			1
Threat Avoidance	1		1				3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3			1			1
Disposables Status	1	2	1	2	2	2	3	3	3	1	2	2	2	1	1	1	1	1	1	1	1	2	2	1	1	3	2	1	1	1	2	1	2	1	1
ECM Status	1	2	1	2	2	2	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3	1	2	1	2	1	1
ECM Tactics	1		2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	2	2	2	1	2	1	2		1
Mutual Support	1		2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	2	2						
Special Threat	1		2				3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3						
Weapons Information																																			
Ballistics	1		2																																1
Weapons Envelope	1		2				3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3						
Weapons Ready		2	2		1	2	3	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	1	1	1	2	2	2		
Weapons Release		2	2		2	2	3	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2			
Weapons Remaining	1	1	1		1	2	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3	2	3	3			1
Weapons Impact							3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3						1
Weapon Selected	1		1		1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3	2		1			
Bomb Fall Time/Impact Point	1		2		2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	2	3	3	3						
Weapons Options Selected	1	2	1		1		2	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	2	2	2	2	1			
Weapons Delivery Selected	1	2	1		1		2	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	2	2	2	2	1			
Air-to-Air Target																																			
Range	2									1			2	1	1	1	1	1	1	1	1			1	1										
Bearing										1			2	1	1	1	1	1	1	1	1			1	1										
Overtake										1			2	1	1	1	1	1	1	1	1			1	1										
Altitude Differential										1			2	1	1	1	1	1	1	1	1			1	1										
Target Turn Rate	2									1			2	1	1	1	1	1	1	1	1			1	1										
Target Attitude										1			2	1	1	1	1	1	1	1	1			1	1										
Identification	1									1			2	1	1	1	1	1	1	1	1			1	1										
Target Altitude										1			2	1	1	1	1	1	1	1	1			1	1										
In Range										1			2	1	1	1	1	1	1	1	1			1	1										
Aim Point										1			2	1	1	1	1	1	1	1	1			1	1										
Breakaway										1			2	1	1	1	1	1	1	1	1			1	1										
Air-to-Ground Target Acquisition																																			
Target Range																																			
Target Bearing																																			
Positive Target ID																																			
Aim Point																																			
Break Away (Pullup)																																			

Legend:
1 Required information
2 Frequently required information
3 Additional value
( ) Optional phases

FIGURE 5.12 INFORMATION REQUIREMENTS FOR COUNTER AIR (CONCLUDED).

6.0 PILOT PERFORMANCE AND BIOCYBERNETIC APPLICATIONS

The preceding sections have provided a framework for discussing pilot tasks. As we noted earlier, the assignment and sequencing of tasks are dependent upon the aircraft characteristics, the tactical objectives, and the information requirements.

Subsection 6.1 attempts to convey the dynamic, time-varying nature of pilot tasks. Subsection 6.2 then describes the biological signals which reflect the pilot's status or which may permit a direct coupling of the pilot with aircraft subsystems. Finally, Subsection 6.3 examines the manner in which biocybernetic techniques can be expected to improve pilot performance and thus enhance weapons system effectiveness.

6.1 TIME LINE ANALYSES OF PILOT TASKS

To avoid the redundancy of presenting detailed task listings for each mission type, we have generated time lines for those tasks commonly associated with segments of a carrier launched escort mission. Figure 6.1 shows that most of the mission segments integrate several of the general mission requirements illustrated previously in Figure 3.4. Further, we have included both air-to-air and air-to-ground scenarios, as evident from the representative mission profile depicted in Figure 6.2.

MISSION SEGMENT	MISSION REQUIREMENT	MISSION SEGMENT	MISSION REQUIREMENT
Launch	1.6 Takeoff	Air-to-Ground (A/G) Strike	2.5 Coordination 2.7 Penetration 2.8 Threat Warning 2.9 Detection 2.10 Location 2.11 Identification 2.12 Decision 2.13 Execution 2.14 Assessment 2.15 Termination
Climb	2.1 Climb to Level-Off	Egress	2.16 Egress 2.5 Coordination 2.8 Threat Warning
Rendezvous	2.2 Cruise 2.5 Coordination 2.6 Mission Rendezvous	In-Flight Refuel	2.17 Cruise 2.18 Rendezvous and AAR
Ingress	2.7 Penetration 2.8 Threat Warning	Marshal	2.20 Return to Base 2.21 Descent
Medium Range Intercept (MRI)	2.5 Coordination 2.8 Threat Warning 2.9 Detection 2.10 Location 2.11 Identification 2.12 Decision 2.13 Execution 2.14 Assessment 2.15 Termination	Prelanding	2.22 Approach
Surface-to-Air-Missile (SAM) Avoidance	2.5 Coordination 2.8 Threat Warning 2.10 Location 2.12 Decision 2.13 Execution	Landing	2.23 Landing
Air Combat Manuevering (ACM)	2.5 Coordination 2.8 Threat Warning 2.9 Detection 2.10 Location 2.11 Identification 2.12 Decision 2.13 Execution 2.14 Assessment 2.15 Termination		

FIGURE 6.1 SEGMENTS OF A CARRIER LAUNCHED ESCORT MISSION. (THE FIGURE SHOWS THE RELATIONSHIPS BETWEEN SEGMENTS AND MISSION REQUIREMENTS PRESENTED PREVIOUSLY IN FIGURE 3.4. SOME OF THE SEGMENTS (E.G., MRI) ARE COMPRISED OF SEVERAL MISSION REQUIREMENTS.)

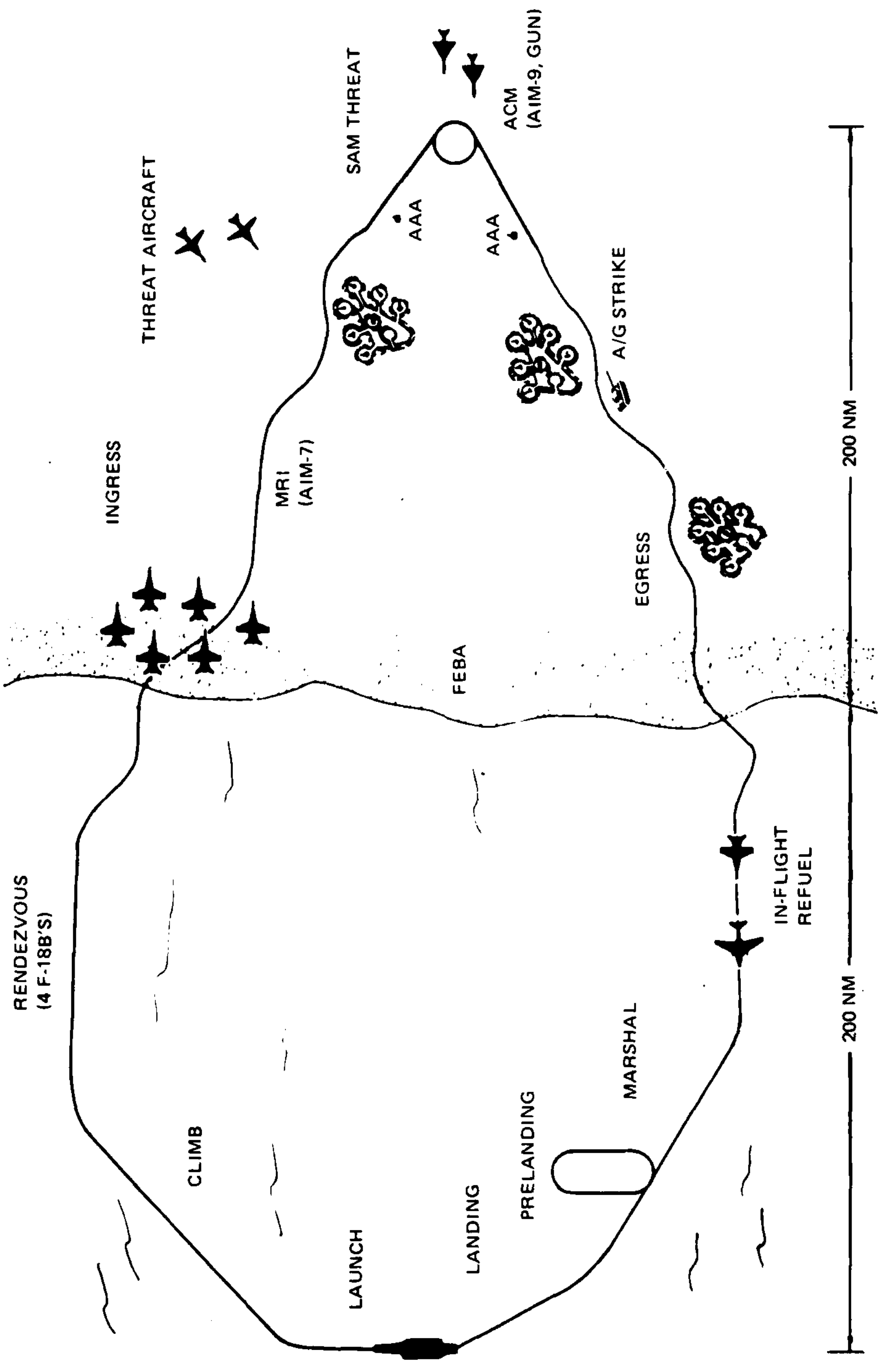


FIGURE 6.2 REPRESENTATIVE PROFILE FOR A CARRIER LAUNCHED ESCORT MISSION.

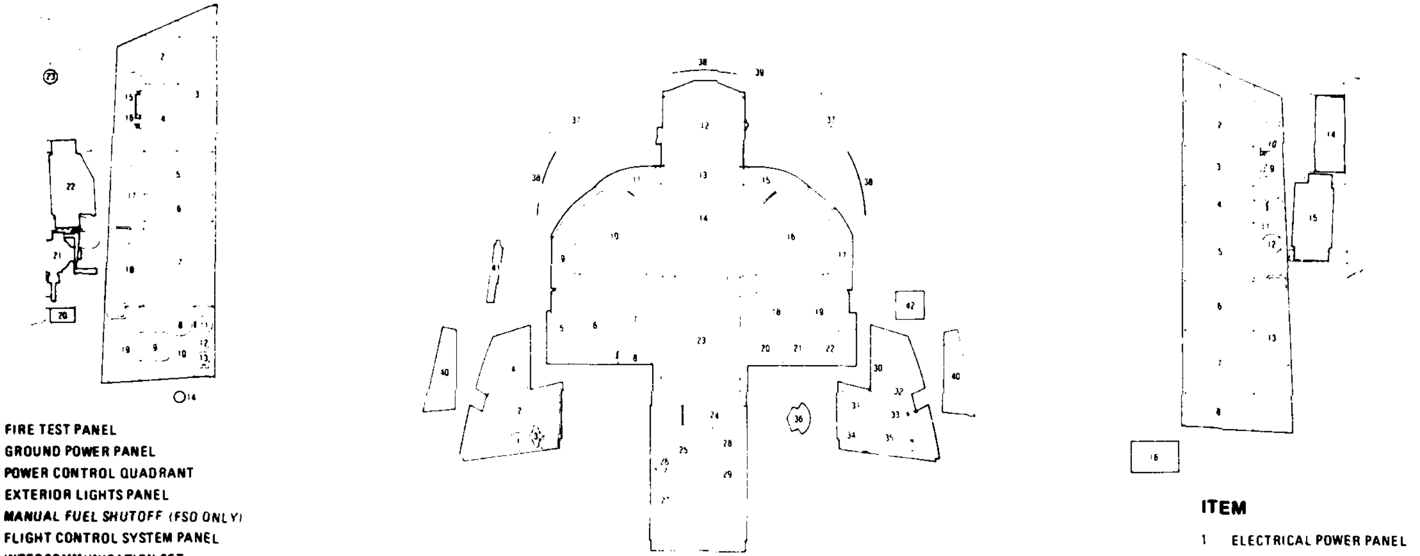
In the construction of dynamic task flows (Figures 6.5 through 6.17), we have incorporated existing documentation on the multimission F/A - 18 aircraft (Wise and Asiala, 1977). The crew station of this aircraft (see Figure 6.3) has been designed for both air-to-air and air-to-ground modes, and it features many of the avionics advances highlighted in Section 3.

We stated in the Introduction that we would restrict the application of biocybernetic techniques to those pilot tasks which are very difficult, are critical to the success of the mission, or occur during periods of heavy workload. In order to eliminate less essential tasks from later consideration (more inclusive listings of tasks appear in the time line analyses), military pilots familiar with the F/A - 18 crew station and with the projected mission requirements rated each task on the basis of difficulty and criticality. The following factors were taken into account when judging task difficulty:

- o amount of information that must be processed,
- o degree to which the relevant cues are discernible,
- o number of control actions and precision with which they must be performed,
- o time available to perform the task (or a cluster of related tasks),
- o dependence upon an integrative process in reaching a decision,
- o other variables (such as stress, fear, or fatigue).

While the relation of the task to the success of the mission was emphasized in estimating criticality, the pilots also indicated whether performance of the task affected flight safety.

LEFT CONSOLE **MAIN INSTRUMENT PANEL** **RIGHT CONSOLE**



LEFT CONSOLE

1. FIRE TEST PANEL
2. GROUND POWER PANEL
3. POWER CONTROL QUADRANT
4. EXTERIOR LIGHTS PANEL
5. *MANUAL FUEL SHUTOFF (FSD ONLY)*
6. FLIGHT CONTROL SYSTEM PANEL
7. INTERCOMMUNICATION SET
8. LOX QUANTITY INDICATOR
9. ANTI g VALVE
10. PILOT SERVICES PANEL
11. ANTI g COUPLING
12. SUIT VENT
13. OXYGEN HOSE
14. COMMUNICATION CONNECTION
15. LIGHTPLATE FUEL DUMP (FSD ONLY)
16. FUEL DUMP CONTROL (FSD ONLY)
17. APU CONTROL PANEL
18. ANTENNA SELECT PANEL
19. HYDRAULICS ISOLATE PANEL
20. NUC DISABLE SWITCH
21. MANUAL CANOPY DRIVE UNIT
22. *L/H CIRCUIT BREAKER PANEL*
23. ECM DISPENSER

MAIN INSTRUMENT PANEL

ITEM

1. BRAKE PRESSURE INDICATOR
2. L/H VERTICAL CONSOLE CONTROL
3. EMERGENCY/PARK BRAKE CONTROL
4. LANDING GEAR CONTROL
5. INDICATOR PANEL
6. DIGITAL ENGINE MONITOR DISPLAY
7. FUEL QUANTITY INDICATOR
8. HDG & CRS LIGHTPLATE
9. MASTER ARM PANEL
10. MASTER MONITOR DISPLAY
11. LEFT THREAT DISPLAY
12. HEAD UP DISPLAY
13. CAMERA MOTION PICTURE
14. UP FRONT CONTROL PANEL
15. RIGHT THREAT DISPLAY
16. MULTIFUNCTION DISPLAY
17. MAP GAIN CONTROL
18. ATTITUDE REFERENCE INDICATOR
19. COVER PLATE (RESERVED FOR ECM)
20. STANDBY AIRSPEED INDICATOR
21. STANDBY ALTIMETER
22. VERTICAL SPEED INDICATOR
23. HORIZONTAL SITUATION DISPLAY
24. COVER PLATE (RESERVED FOR ECM)
25. ECM CONTROL PANEL
26. RUDDER PEDAL ADJUSTMENT
27. BUND LIGHTPLATE
28. CLOCK
29. ALTIMETER, PRESSURE COMPARTMENT
30. ARRESTING HOOK CONTROL
31. HEIGHT INDICATOR
32. LANDING LIGHTPLATE
33. WINGFOLD CONTROL
34. HYDRAULIC PRESSURE INDICATOR
35. CAUTION LIGHT PANEL
36. STATIC SOURCE SELECTOR
37. HANDLE CANOPY BOW
38. MIRROR
39. SHOOT LOCK INDICATOR
40. ECS LOUVER
41. CANOPY JETTISON LEVER
42. STANDBY MAGNETIC COMPASS

RIGHT CONSOLE

ITEM

- 1 ELECTRICAL POWER PANEL
- 2 ECS CONTROL PANEL
- 3 INTERIOR LIGHTS PANEL
- 4 SENSOR CONTROL PANEL
- 5 BLANK PANEL
- 5A *SECURE SPEECH CONTROL*
- 6 BLANK PANEL
- 7 BLANK PANEL
- 7A RESERVED FOR AMAC PANEL
- 8 BLANK PANEL
- 9 DEFOG LIGHTPLATE
- 10 DEFOG CONTROL
- 11 FLOODLIGHT SUPPORT PANEL
- 12 FLOODLIGHT
- 13 MAP AND DATA CASE
- 14 CANOPY CONTROL
- 15 R/H CIRCUIT BREAKER PANEL
- 16 FAN TEST CONTROL

FIGURE 6.3 SCHEMATIC CONFIGURATION OF F/A 18 CREW STATION.

We have defined workload in terms of the number of tasks a pilot must perform in an arbitrary period of time. For each mission segment, we counted the number of individual tasks, including repetitions of the same task, which are presumed to occur in a 5 second interval (see Figure 6.4). Tasks which continue in successive intervals were counted for both time periods. Descriptive statistics were derived from these tabulations. Across the entire mission, mean "task load" per 5 second interval was equal to 3.93 tasks, with a standard deviation of 1.77 tasks. High task load intervals were assumed to have task frequencies greater than 7.47 (two standard deviations above the mean). The tasks which appear in these intervals and the tasks assigned high ratings with regard to difficulty or criticality comprise the row headings of the biocybernetic matrices in Subsection 6.3.

The time lines which follow are meant to be illustrative, since the duration of any mission segment will change dramatically as conditions change. To demonstrate the process of creating dynamic task flows, we have presented complete time lines for launch, surface-to-air missile (SAM) avoidance, air combat maneuvering (ACM), and landing. For the remainder of the mission segments, time lines are provided for only the high task load intervals. In general, the task listings should be read from bottom to top. Further, the reader may find it helpful to refer again to the relevant mission and information requirements described in Sections 4 and 5, respectively. A brief narrative introduces each mission segment.

NUMBER OF TASKS PERFORMED IN A FIVE SECOND PERIOD

MISSION SEGMENT	0	1	2	3	4	5	6	7	8	9	10	11	12	12+	$\overline{X}$
LAUNCH	0	0	0	0	1	0	2	2	3	2	1	0	1	0	7.83
CLIMB	0	9	11	16	6	6	1	0	2	0	0	0	0	0	3.04
RENDEZVOUS	1	12	14	28	9	2	1	1	0	1	1	0	0	0	2.90
INGRESS	0	0	2	3	3	4	6	1	1	0	0	0	0	0	4.80
MEDIUM RANGE INTERCEPT	0	17	2	3	2	2	1	2	1	0	0	0	0	1	2.94
SAM AVOIDANCE	0	1	1	2	0	4	1	0	0	1	0	1	0	0	5.00
AIR COMBAT MANEUVERING	0	0	0	1	4	6	19	14	6	4	1	2	3	0	6.88
A/G STRIKE	0	0	3	6	6	7	4	1	0	0	0	0	0	0	4.22
EGRESS	0	0	5	8	4	4	1	0	0	0	0	0	0	0	3.45
IN-FLIGHT REFUEL	2	13	30	39	59	28	6	5	1	1	0	0	0	0	3.55
MARSHAL	0	11	12	11	14	9	8	4	1	0	0	0	0	0	3.56
PRELANDING	0	0	1	4	10	4	8	7	3	2	1	0	0	0	5.58
LANDING	1	15	15	13	7	2	1	1	2	0	0	0	0	0	2.65
TOTAL	4	78	96	134	125	78	59	38	20	11	4	3	4	1	3.93

FIGURE 6.4 ANTICIPATED TASK LOADINGS DURING SEGMENTS OF A CARRIER LAUNCHED ESCORT MISSION. (FROM THE TIME LINE ANALYSES OF TASKS WHICH ARE ASSIGNED TO THE PILOT DURING EACH SEGMENT (SEE FIGURES 6.5 THROUGH 6.17), THIS TABLE SUMMARIZES THE NUMBER OF TASKS WHICH MUST BE PERFORMED ACROSS ALL FIVE SECOND INTERVALS. THUS, FOR AIR COMBAT MANEUVERING, THE ENTRY OF "19" IN THE TASKS COLUMN LABELED "6" INDICATES THAT 6 TASKS MUST BE PERFORMED DURING 19 OF THE 60 (TOTAL) FIVE SECOND INTERVALS. FOR THIS SEGMENT, THE MEAN OF 6.88 IS THE AVERAGE TASK LOADING PER FIVE SECOND INTERVAL.)

6.1.1 Launch - Within this 60 second segment, the pilot catapults from the carrier, establishes and maintains proper attitude for climb, and retracts the landing gear and flaps for normal flight. Throughout the segment, critical flight data are processed and attitude adjustments are performed. Visual search of surrounding airspace is required to monitor the position of the other escort aircraft (assuming a dual launch).

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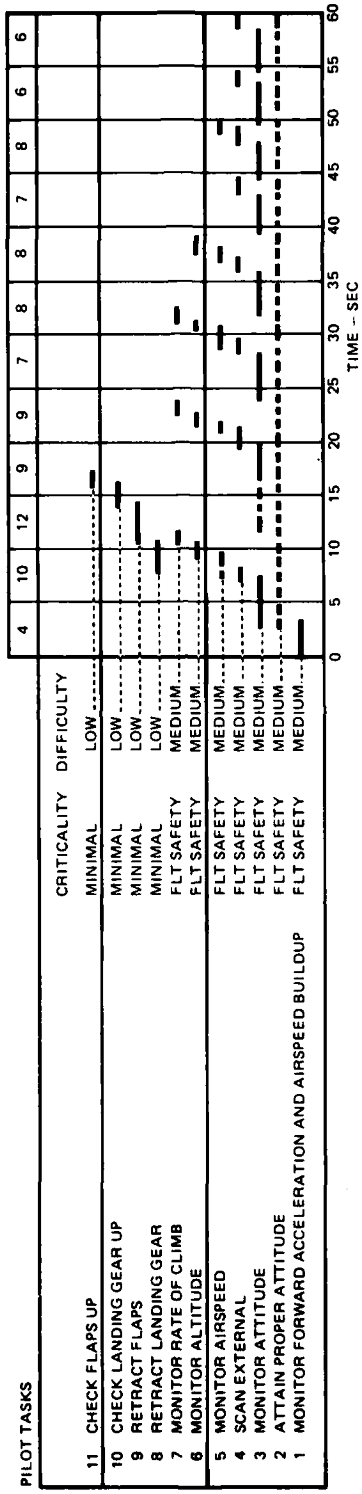

FIGURE 6.5 DYNAMIC TASK FLOWS FOR LAUNCH.

6.1.2 Climb - The lead pilot joins with his wingman, and they climb to their assigned altitude. Both pilots are in constant communication with the air traffic controller and with each other. Climb and level-off checks are frequent, as is the monitoring of other flight parameters. Once clear of the carrier, the pilots establish proper spacing between their aircraft and then engage the Automatic Flight Control System (AFCS). The flight monitoring tasks continue throughout the mission segment. Additionally, the Identification-Friend or Foe (IFF) system is activated, and preliminary subsystems checks are performed.

PILOT TASKS

		CRITICALITY	DIFFICULTY
23	GIVE WING LEVEL-OFF SIGNAL	FLT SAFETY	LOW
22	ENGAGE ALTITUDE HOLD	MINIMAL	LOW
21	CHECK ALTITUDE/SET ALTIMETER	MINIMAL	LOW
20	VERIFY FUEL TRANSFER AND SEQUENCE	MISSION	LOW
19	CHECK CABIN ALTITUDE	FLT SAFETY	LOW
18	CHECK OXYGEN QUANTITY	FLT SAFETY	LOW
17	DEPRESS ENTER	MINIMAL	LOW
16	CHECK CODE	MINIMAL	LOW
15	INPUT IDENTIFY–FRIEND OR FOE CODE	MINIMAL	LOW
14	SELECT IDENTIFY–FRIEND OR FOE	MINIMAL	LOW
13	MONITOR VERTICAL VELOCITY	MINIMAL	MEDIUM
12	MONITOR ALTITUDE	MINIMAL	MEDIUM
11	RECEIVE COMMUNICATION	MISSION	LOW
10	COMMUNICATE	MISSION	LOW
9	UNLOCK SHOULDER HARNESS	MINIMAL	LOW
8	CLEAR VISUAL AIRSPACE/WINGMAN POSITION	FLT SAFETY	MEDIUM
7	ATTAIN DESIRED THRUST	MISSION	MEDIUM
6	MONITOR AIRSPEED	MINIMAL	MEDIUM
5	ENGAGE AUTOMATIC FLIGHT CONTROL SYSTEM	MINIMAL	LOW
4	ATTAIN DESIRED ATTITUDE	FLT SAFETY	MEDIUM
3	MONITOR NAVIGATION	MISSION	MEDIUM
2	MONITOR HEADING	MINIMAL	MEDIUM
1	MONITOR ATTITUDE	MINIMAL	MEDIUM

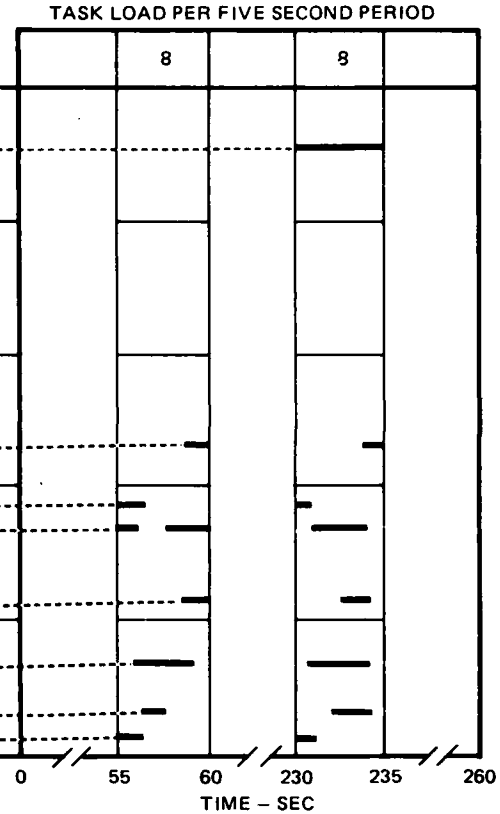

FIGURE 6.6 DYNAMIC TASK FLOWS FOR CLIMB.

6.1.3 Rendezvous - The escort pilots are principally concerned with joining the strike force. Radar parameters are selected (to assist in the location process) and then a system check is performed. The pilot also must achieve UHF communication with the strike force. Since most of the flying is conducted under AFCS, task load is relatively low. The pilot continuously monitors displayed flight data and the position of the other escort aircraft. Once the strike force is joined, the pilot disengages the AFCS to begin formation flying.

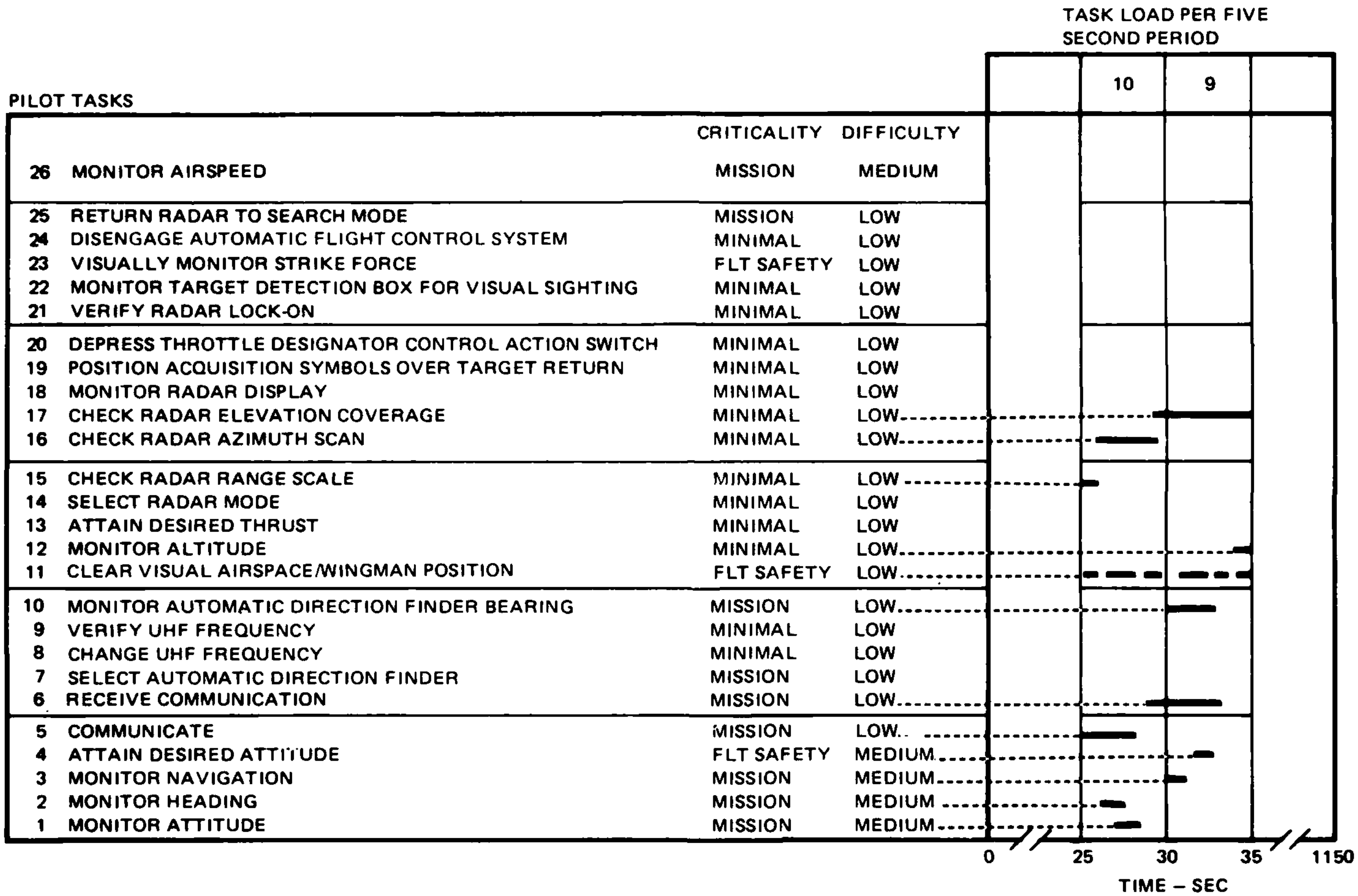

FIGURE 6.7 DYNAMIC TASK FLOWS FOR RENDEZVOUS.

6.1.4 Ingress - This segment commences as the aircraft cross the forward edge of the battle area (FEBA). Counter-threat and armament subsystems are set and checked, and the pilot flies a level weave maneuver until the strike force reaches the target or until ingress is interrupted. To reduce the possibility of detection by enemy ground forces, the radar altimeter is deactivated.

PILOT TASKS

		CRITICALITY	DIFFICULTY
27	ATTAIN DESIRED ATTITUDE	FLT SAFETY	MEDIUM
26	MONITOR HEADING	MINIMAL	LOW
25	MONITOR AIRSPEED	MISSION	LOW
24	MONITOR ATTITUDE	MINIMAL	LOW
23	MONITOR RADAR DISPLAY	MISSION	LOW
22	CHECK FUEL STATUS	MISSION	LOW
21	MONITOR ENGINE INSTRUMENTS	MISSION	LOW
20	MAINTAIN VISUAL SURVEILLANCE	FLT SAFETY	LOW
19	SET RADAR STORAGE (TARGET DISPLAY) TIME	MISSION	MEDIUM
18	CHECK AIR-TO-AIR ARMAMENT STATUS	MISSION	LOW
17	VERIFY SPARROW MISSILE SELECTED	MISSION	LOW
16	SELECT AIR-TO-AIR MODE	MISSION	LOW
15	VERIFY MODE SELECT (PROGRAM)	MISSION	LOW
14	CHECK JAMMER DISPENSE COUNTER	FLT SAFETY	LOW
13	CHECK FLARE DISPENSE COUNTER	FLT SAFETY	LOW
12	CHECK CHAFF DISPENSE COUNTER	FLT SAFETY	LOW
11	VERIFY AUTOMATIC CHAFF DISPENSE ENABLE	FLT SAFETY	LOW
10	VERIFY CHAFF DISPENSE ENABLE	FLT SAFETY	LOW
9	ADJUST BRIGHTNESS OF THREAT DISPLAY	FLT SAFETY	LOW
8	ATTAIN DESIRED THRUST	MISSION	MEDIUM
7	SET RADAR VOLUMES	MISSION	LOW
6	VERIFY ELECTRONIC COUNTERMEASURE SELECTED	FLT SAFETY	LOW
5	VERIFY SAM RECEIVER ON	FLT SAFETY	LOW
4	TURN RADAR ALTIMETER OFF	MISSION	LOW
3	TURN TACTICAL AIR NAVIGATION TO RECEIVE	MISSION	LOW
2	TURN IDENTIFY-FRIEND OR FOE TO STANDBY	MISSION	LOW
1	VERIFY CROSSING OF THE FORWARD EDGE OF BATTLE AREA	MISSION	LOW

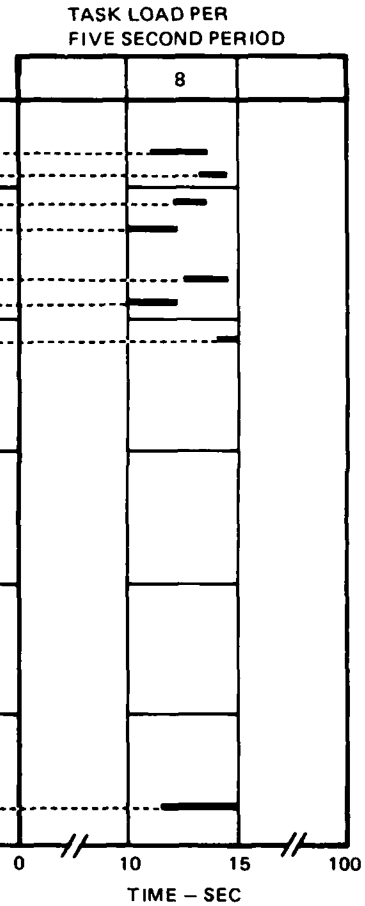

FIGURE 6.8 DYNAMIC TASK FLOWS FOR INGRESS.

6.1.5 Medium Range Intercept (MRI) - Should enemy fighters be encountered, the escort aircraft must defend the strike force. Therefore, fire control functions have the highest priority within this segment. Pilot responsibilities include:

- o configuring the aircraft subsystems for the appropriate attack mode,
- o selecting azimuth and elevation coordinates for radar antenna,
- o monitoring radar display and IFF evaluator,
- o arming and assessing status of selected missile,
- o achieving target lock-on,
- o maneuvering so that the enemy aircraft is positioned within the missile launch envelope,
- o firing the missile,
- o observing flight path of the missile.

The outcome of the engagement is communicated, the master arm is set to safe, and navigation data are processed. The pilot then will proceed to rejoin the strike force.

PILOT TASKS

		CRITICALITY	DIFFICULTY
33	CHECK NAVIGATION DATA	MISSION	LOW
32	SET MASTER ARM TO SAFE	FLT SAFETY	LOW
31	OBSERVE FLASHING BREAKAWAY CUE	FLT SAFETY	LOW
30	OBSERVE MISSILE TIME OF FLIGHT	MISSION	LOW
29	VERIFY MISSILE LAUNCH	MISSION	LOW
28	DEPRESS TRIGGER	MISSION	LOW
27	OBSERVE IN RANGE CUE	MISSION	LOW
26	OBSERVE LAUNCH LIMITS, STEERING, ALLOWABLE STEERING ERROR	MISSION	MEDIUM
25	FLY STEERING DOT COMMANDS	MISSION	MEDIUM
24	JETTISON FUEL TANKS	FLT SAFETY	MEDIUM
23	CHECK SPARROW MISSILE STATUS	MINIMAL	LOW
22	SCAN EARLY WARNING DISPLAY TARGET STROBE BEARING	MINIMAL	LOW
21	NOTE AIR INTERCEPT WARNING LIGHT	MINIMAL	LOW
20	ATTAIN DESIRED THRUST	MISSION	LOW
19	OBSERVE RADAR TRACKING TARGET/ASSESS DATA	MINIMAL	LOW
18	VERIFY LOCK-ON	MINIMAL	MEDIUM
17	DEPRESS THROTTLE DESIGNATOR CONTROL TO LOCK-ON	MISSION	LOW
16	POSITION ACQUISITION SYMBOL	MISSION	MEDIUM
15	RECEIVE ACKNOWLEDGMENT	MISSION	LOW
14	COMMUNICATE	MISSION	LOW
13	SET MASTER ARM TO ARM	MISSION	LOW
12	MONITOR RADAR	MISSION	MEDIUM
11	ATTAIN DESIRED ATTITUDE	FLT SAFETY	MEDIUM
10	MONITOR ATTITUDE	MISSION	MEDIUM
9	MONITOR HEADING	MISSION	MEDIUM
8	MONITOR AIRSPEED	MISSION	MEDIUM
7	MONITOR ALTITUDE	MISSION	MEDIUM
6	SCAN OUTSIDE	FLT SAFETY	MEDIUM
5	MONITOR FUEL STATUS	FLT SAFETY	LOW
4	OBSERVE AZIMUTH SCAN	MISSION	LOW
3	OBSERVE ALTITUDE COVERAGE	MISSION	LOW
2	SET ANTENNA ELEVATION	MISSION	LOW
1	SELECT VELOCITY SEARCH MODE	MISSION	LOW

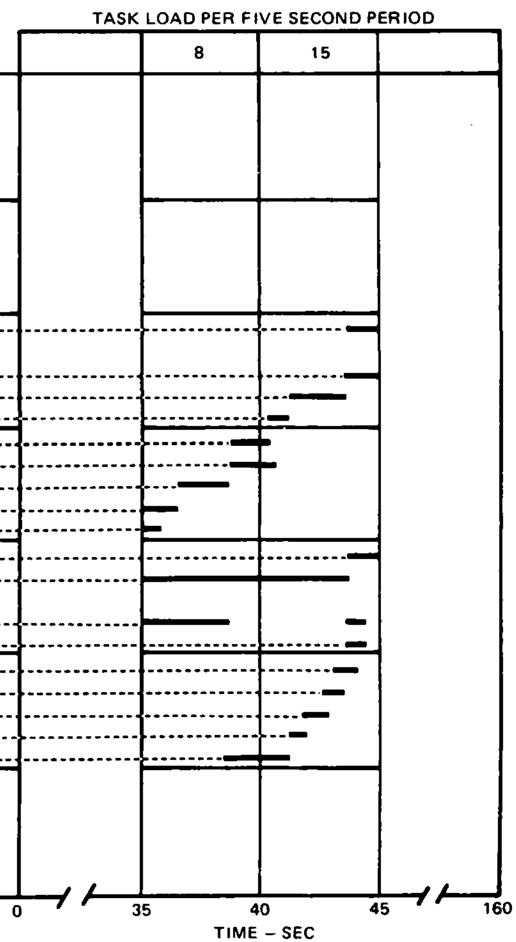

FIGURE 6.9 DYNAMIC TASK FLOWS FOR MEDIUM RANGE INTERCEPT (MRI).

6.1.6 Surface-to-Air-Missile (SAM) Avoidance - Should a warning of possible SAM launch be displayed to the pilot, he must determine the azimuth of the SAM site and inform the other pilots of the direction of the threat. If a SAM launch is confirmed, the pilot must begin to search visually for the missile. He also will dispense chaff and flares to decoy the missile or will initiate jamming to confuse the missile's radar. If the missile cannot be detonated or avoided in this manner, the pilot must perform evasive flight maneuvers. He will track the smoke trail of the missile so that he may time the necessary abrupt changes in altitude, velocity, and direction.

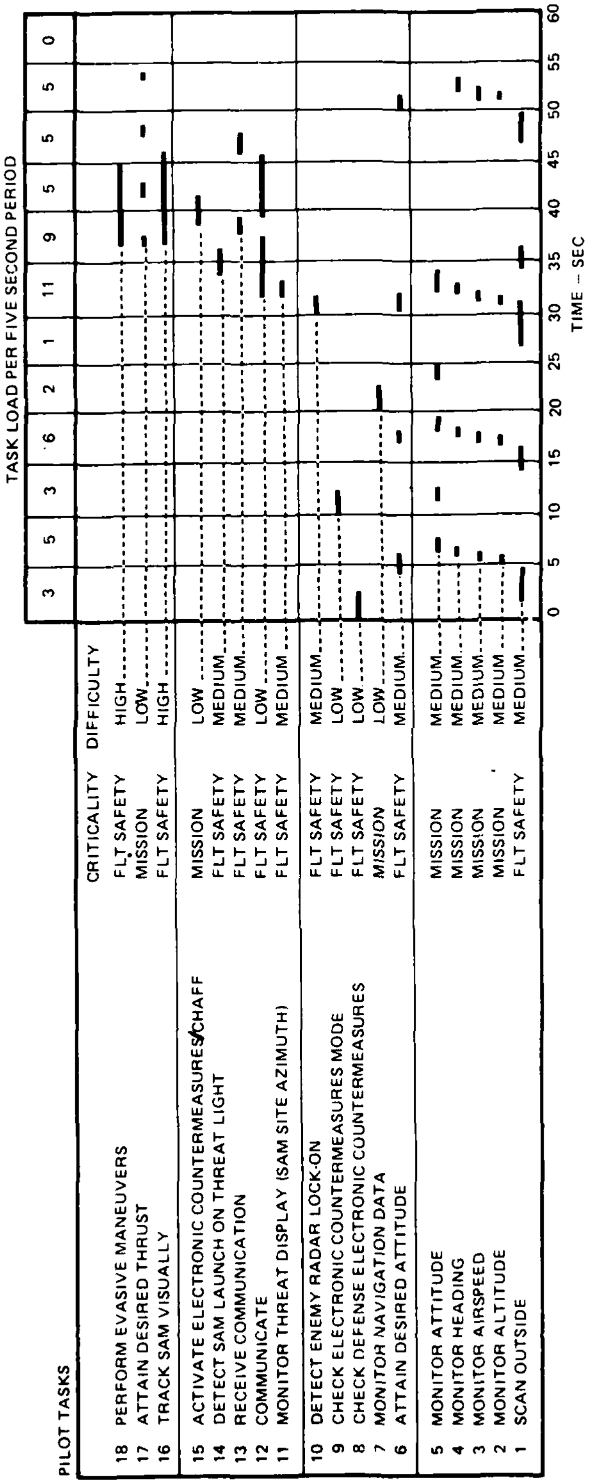

FIGURE 6.10 DYNAMIC TASK FLOWS FOR SAM AVOIDANCE.

6.1.7 Air Combat Maneuvering (ACM) - When "beyond visual range" threats are first encountered, long or medium range missiles (Subsection 6.1.5) are deployed. Should these weapons prove ineffective (due to enemy maneuvering or an inability to achieve lock-on) or should enemy aircraft successfully avoid radar defenses, then close-in combat will result. Consequently, within this segment we are concerned with those tasks related to either AIM-9 (Sidewinder) missile or gun attack. It should be noted that crucial flight and weapons data are displayed on the HUD in order to maximize the time available to the pilot for visually tracking the enemy aircraft. A complicating factor is the high g environment in which the tasks must be performed, since violent manuevering is required to properly align the weapons with the target and to position the target within the missile launch or gun envelope.

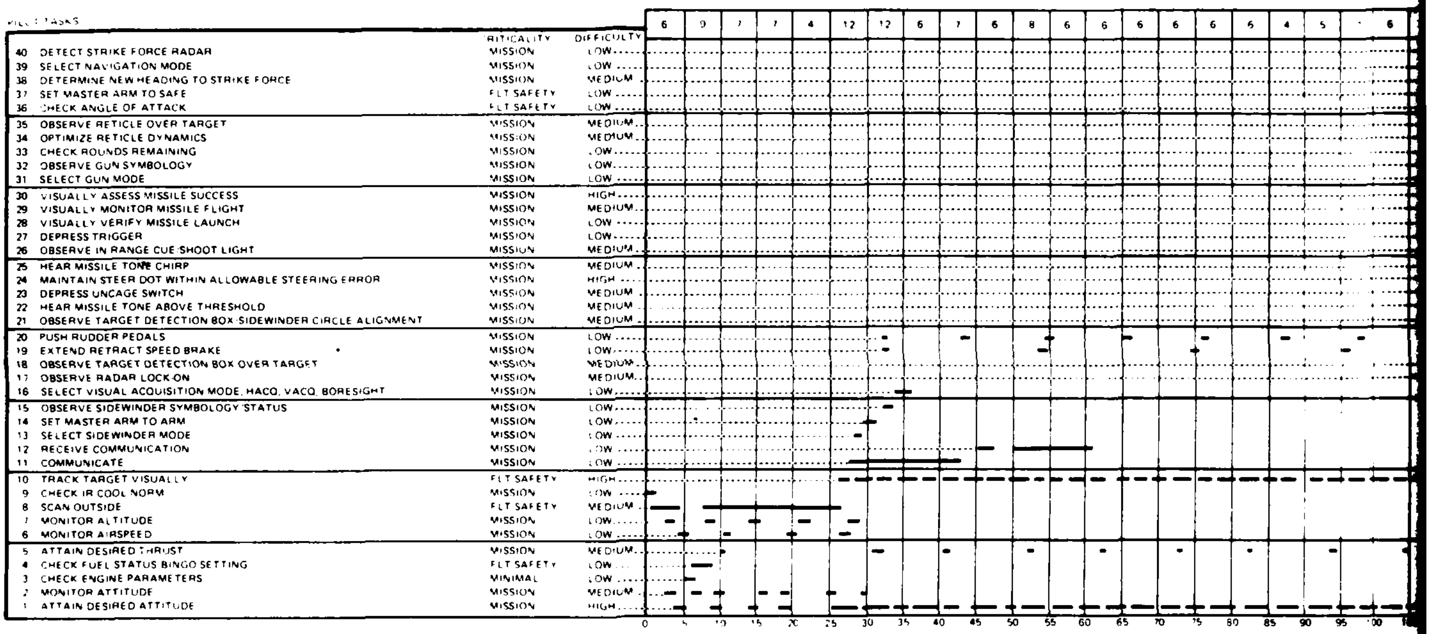

FIGURE 6.11 DYNAMIC TASK FLOWS FOR AIR COMBAT MANEUVERING (ACM).

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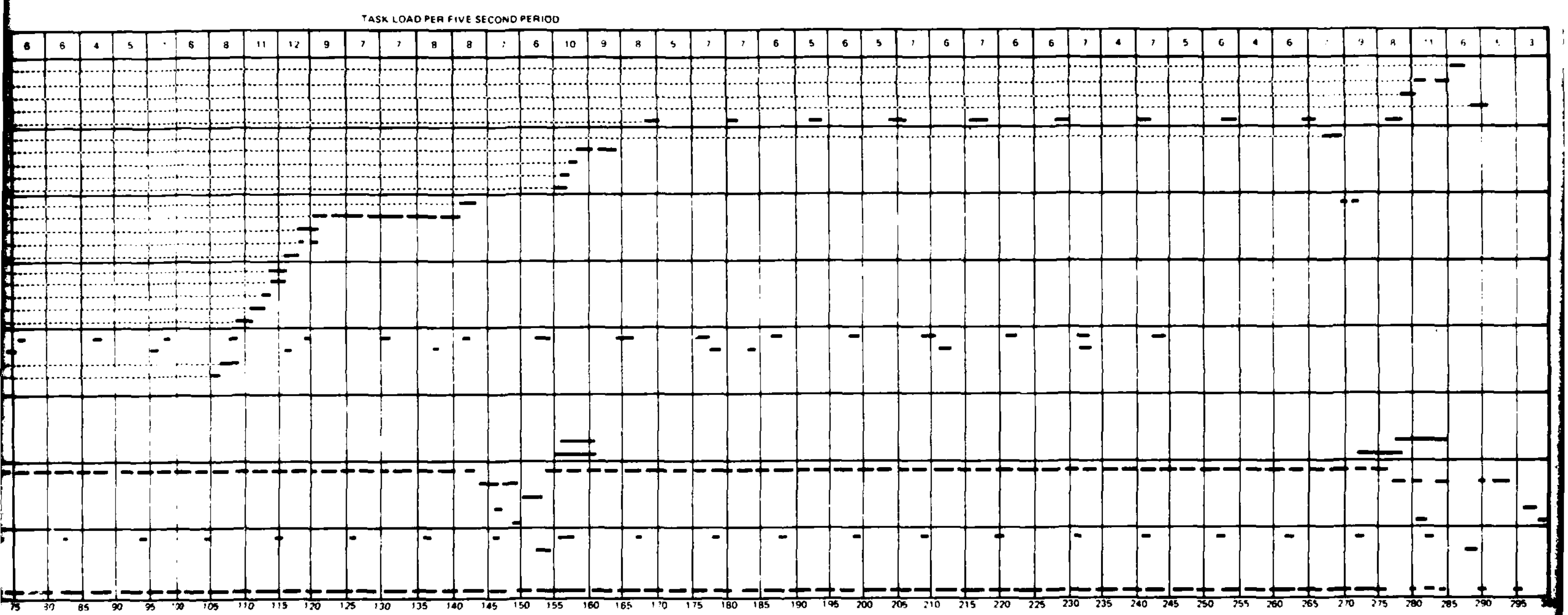


v

6.1.8 Air-to-Ground (A/G) Strike - Escort aircraft may participate in attack of ground targets, especially during Air Interdiction. We have assumed low altitude penetration and that the location of the targets is stored within the TACAN computer prior to the mission. Moreover, we have assumed delivery of ballistic weapons and, given consent, that the actual time of release is computed automatically. The pilot must select the appropriate armament program and determine that he is in the vicinity of the target area before he initiates "pop-up." When he reaches target-unmask altitude and acquires the target visually, the pilot will maneuver the aircraft until the target is observed to be within the HUD field-of-view. He then will depress the "pickle" (weapons release) button and continue to track the target until the flashing symbology indicates release of the bomb. This cue also signals pull-up, and the pilot subsequently will establish heading for egress from the target area.

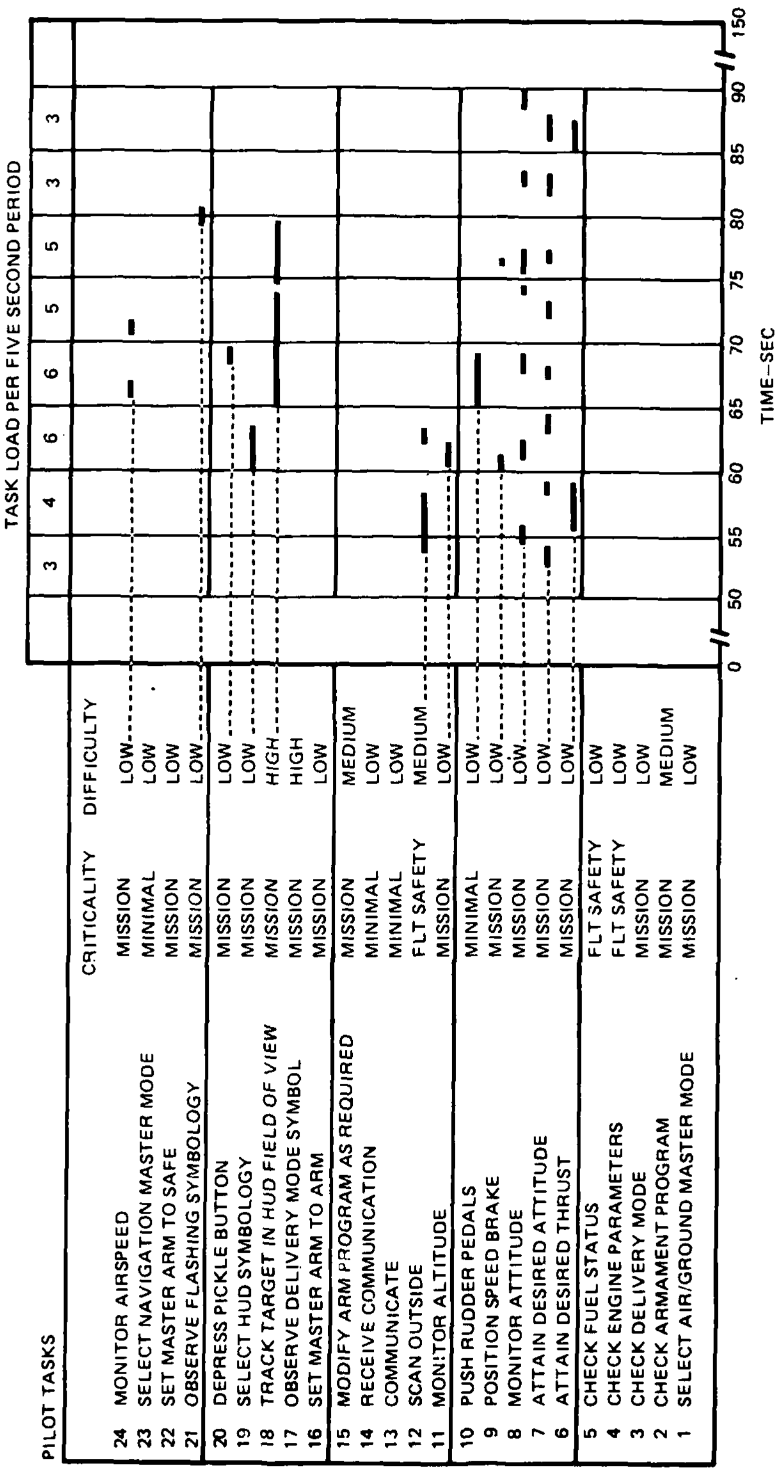


FIGURE 6.12 DYNAMIC TASK FLOWS FOR AIR-TO-GROUND STRIKE.

6.1.9 Egress - This segment commences as the aircraft leave the target area. The pilot frequently processes flight data, adjusts flight controls, and monitors surrounding airspace. Further, counter-threat and armament subsystems are reset and rechecked.

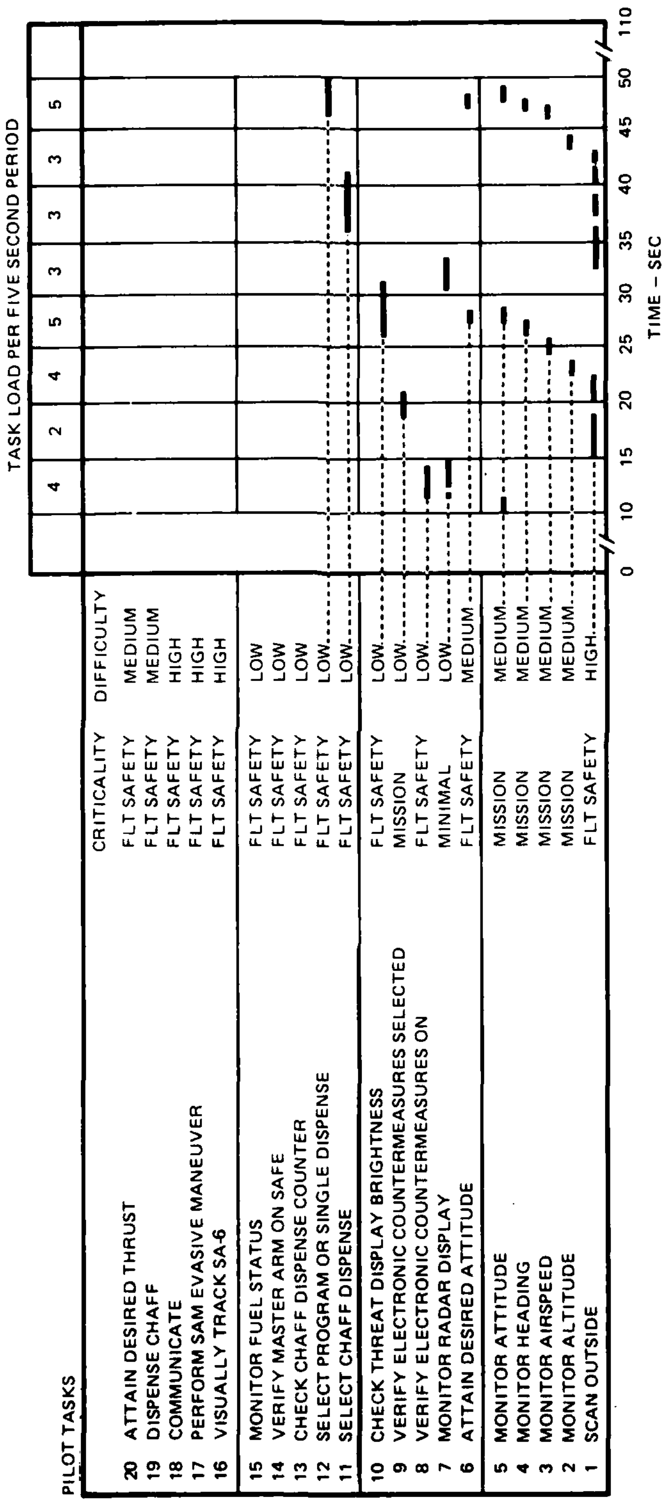


FIGURE 6.13 DYNAMIC TASK FLOWS FOR EGRESS.

6.1.10 In-Flight Refuel - While in cruise, the pilot will select altitude, heading and attitude coordinates for the Automatic Flight Control System (AFCS). He also will designate the approximate location of the tanker aircraft and will adjust radar parameters for a more precise determination of the refueling site. Once lock-on is achieved, the pilot will deactivate the AFCS to maintain close formation during approach to the tanker fleet. Rendezvous typically will occur at 20,000 ft., at least 50 nm from the FEBA. The remainder of the tasks within this segment are associated with the actual refueling operation (e.g., extension of the probe, activation of the refueling switches, and retraction of the probe).

PILOT TASK		CRITICALITY	DIFFICULTY
49	CONFIRM POSITION OF ECHELON	FLT SAFETY	LOW
48	POSITION PROBE TO RETARD	MINIMAL	LOW
47	CHECK INDICATOR FOR CORRECT AMOUNT	FLT SAFETY	LOW
46	NOTE TANKER STANDBY GREEN OFF	MISSION	LOW
45	CHECK TANKER STANDBY GREEN ON	MISSION	LOW
44	OBSERVE TRANSFER LIGHT OFF	MISSION	LOW
43	CHECK TRANSFER LIGHT ON	MISSION	MEDIUM
42	CHECK TANKER READY LIGHT ON	MISSION	MEDIUM
41	CHECK DROGUE EXTENDED	MISSION	MEDIUM
40	SET RADAR ALTITUDE TO STANDBY	MINIMAL	LOW
39	SET TARGET CLEARANCE ALTITUDE TO STANDBY	MINIMAL	LOW
38	SET RADAR TO STANDBY	MINIMAL	LOW
37	SET REFUELING SWITCHES	MISSION	MEDIUM
36	CHECK PROBE FULLY EXTENDED	MISSION	MEDIUM
35	POSITION PROBE TO EXTEND	MISSION	LOW
34	SET EXTERNAL LIGHTS TO STANDBY BRIGHT	MINIMAL	LOW
33	DESELECT AUTOMATIC DIRECTION FINDER	FLT SAFETY	LOW
32	DEACTIVATE AUTOMATIC FLIGHT CONTROL SYSTEM	FLT SAFETY	LOW
31	FLY FORMATION/THRUST	FLT SAFETY	HIGH
30	FLY FORMATION/ATTITUDE	FLT SAFETY	HIGH
29	CHANGE TO REFUEL FREQUENCY	MISSION	MEDIUM
28	CHECK MASTER ARM SAFE	FLT SAFETY	LOW
27	VERIFY ALTITUDE SETTING	FLT SAFETY	MEDIUM
26	MONITOR RADAR	FLT SAFETY	MEDIUM
25	VERIFY LOCK-ON	MINIMAL	MEDIUM
24	COMMAND LOCK-ON	MINIMAL	MEDIUM
23	DESIGNATE TARGET FOR LOCK-ON	MINIMAL	MEDIUM
22	CHECK AERIAL REFUELING CENTRAL POINT COORDINATES	MINIMAL	MEDIUM
21	MONITOR RADAR FOR TANKER	MISSION	MEDIUM
20	SELECT SECTOR SCAN	MINIMAL	MEDIUM
19	SELECT BAR SCAN	MINIMAL	MEDIUM
18	SELECT RADAR RANGE	MINIMAL	MEDIUM
17	ENABLE WAYPOINT	MINIMAL	MEDIUM
16	SELECT RENDEZVOUS FREQUENCY	MISSION	LOW
15	SET IN AERIAL REFUELING CENTRAL POINT COORDINATES	MINIMAL	MEDIUM
14	CHECK AUTOMATIC DIRECTION FINDER BEARING	MINIMAL	LOW
13	SELECT AUTOMATIC DIRECTION FINDER	MINIMAL	LOW
12	SELECT TARGET CLEARANCE ALTITUDE CHANNEL AIR-TO-AIR MODE	MINIMAL	MEDIUM
11	COMMUNICATE	MINIMAL	MEDIUM
10	RECEIVE COMMUNICATION	MINIMAL	MEDIUM
9	ATTAIN DESIRED THRUST	MINIMAL	LOW
8	SELECT ALTITUDE HOLD	MINIMAL	LOW
7	SELECT AUTOMATIC FLIGHT CONTROL SYSTEM	MINIMAL	LOW
6	ATTAIN DESIRED ATTITUDE	FLT SAFETY	MEDIUM
5	MONITOR NAVIGATION DATA	MINIMAL	MEDIUM
4	SCAN EXTERNAL	FLT SAFETY	MEDIUM
3	MONITOR HEADING	MINIMAL	MEDIUM
2	MONITOR ALTITUDE	FLT SAFETY	MEDIUM
1	MONITOR AIRSPEED	MISSION	MEDIUM

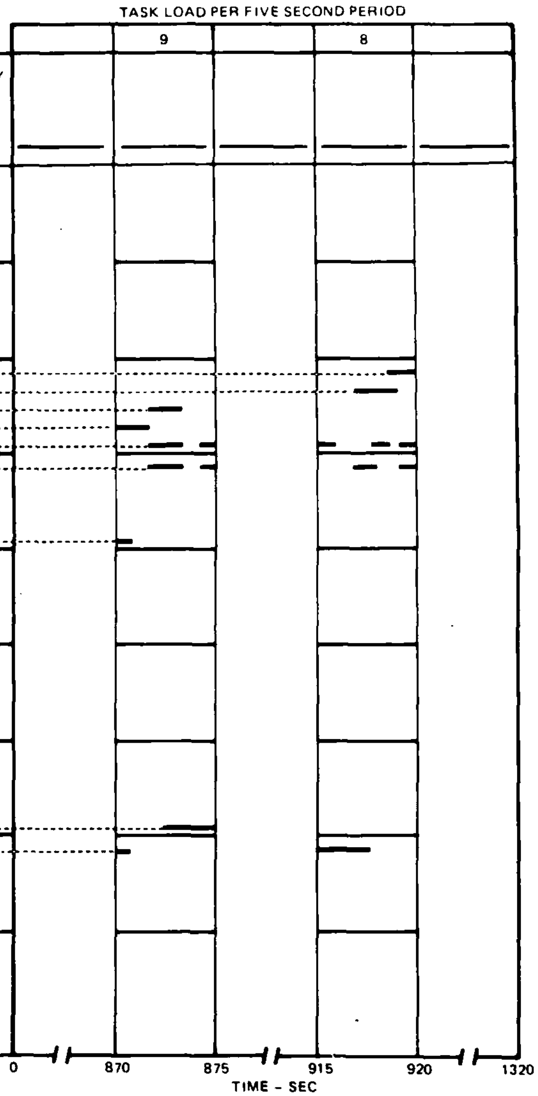


FIGURE 6.14 DYNAMIC TASK FLOWS FOR IN-FLIGHT REFUELING.

6.1.11 Marshal - Prior to approach for carrier landing, the escort and strike aircraft will break formation and will descend to establish a holding pattern until clearance is received. While in the pattern, the pilot will engage the AFCS in order to perform various housekeeping checks and to configure the subsystems for approach and landing. He also will monitor his position in the pattern to assure proper in-flight alignment (IFA) during approach. In addition, IFF codes are again verified to maximize classification of "beyond visual range" threats. Finally, the Instrument Landing System (ILS) is set to standby and the proper heading is selected.

PILOT TASKS

		CRITICALITY	DIFFICULTY
35	CHECK MULTIMODE DISPLAY FOR AUTOMATIC CARRIER LANDING STATUS	FLT SAFETY	LOW
34	VERIFY DATALINK FREQUENCY	MISSION	LOW
33	SELECT HEADING	MISSION	LOW
32	SELECT COURSE	MISSION	LOW
31	SELECT INSTRUMENT LANDING SYSTEM ON STANDBY ATTITUDE DIRECTOR INDICATOR	MISSION	LOW
30	VERIFY INSTRUMENT LANDING SYSTEM CHANNEL	MISSION	LOW
29	VERIFY BEACON CHANNEL	MISSION	LOW
28	SELECT AUTOMATIC CARRIER LANDING	MISSION	LOW
27	DEPRESS ENTER	MISSION	LOW
26	VERIFY IDENTIFY-FRIEND OR FOE CODE	MISSION	LOW
25	ENTER IDENTIFY-FRIEND OR FOE DIGITS	MISSION	LOW
24	SELECT IDENTIFY-FRIEND OR FOE	MISSION	LOW
23	ENGAGE ATTITUDE HOLD	MINIMAL	LOW
22	CHECK FUEL QUANTITY	MISSION	LOW
21	CHECK ENGINE INSTRUMENTS	MISSION	LOW
20	POSITION SPEEDBRAKES	MISSION	LOW
19	ADJUST CABIN AIR AS REQUIRED	MISSION	LOW
18	SELECT RADAR OPERATE	MISSION	LOW
17	SELECT WAYPOINT	MISSION	LOW
16	ACTIVATE RADAR ALTITUDE	MISSION	LOW
15	DEPRESS ENTER	MISSION	LOW
14	SELECT TRANSMIT/RECEIVE AND TACTICAL AIR NAVIGATION	MINIMAL	LOW
13	MONITOR VERTICAL VELOCITY	MISSION	MEDIUM
12	MONITOR ALTITUDE	FLT SAFETY	MEDIUM
11	RECEIVE COMMUNICATION	MISSION	LOW
10	COMMUNICATE	MISSION	LOW
9	SELECT TACTICAL AIR NAVIGATION	MINIMAL	LOW
8	SCAN OUTSIDE	FLT SAFETY	MEDIUM
7	ATTAIN DESIRED THRUST	MISSION	MEDIUM
6	MONITOR AIRSPEED	MISSION	MEDIUM
5	ENGAGE AUTOMATIC FLIGHT CONTROL SYSTEM	MINIMAL	LOW
4	ATTAIN DESIRED ATTITUDE	FLT SAFETY	MEDIUM
3	MONITOR NAVIGATION	MISSION	MEDIUM
2	MONITOR HEADING	MINIMAL	MEDIUM
1	MONITOR ATTITUDE	FLT SAFETY	MEDIUM

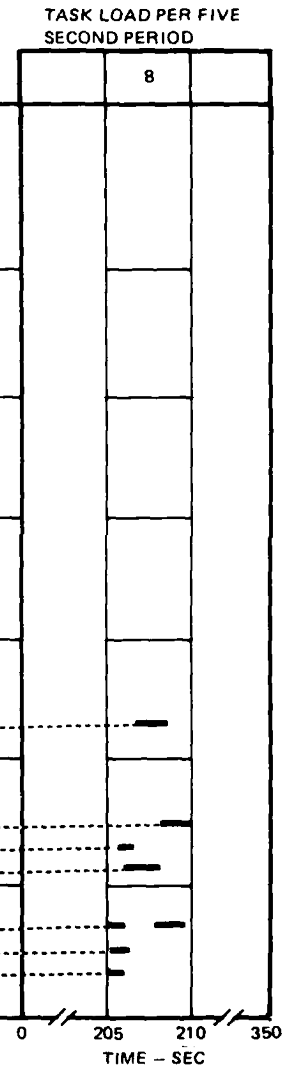


FIGURE 6.15 DYNAMIC TASK FLOWS FOR MARSHAL.

6.1.12 Prelanding - During approach, the pilot's principal objectives are to arrive at the outer marker:

- o in the assigned time slot,
- o at the appropriate altitude, attitude, heading and airspeed.

Therefore, housekeeping functions receive the highest priority within this segment.

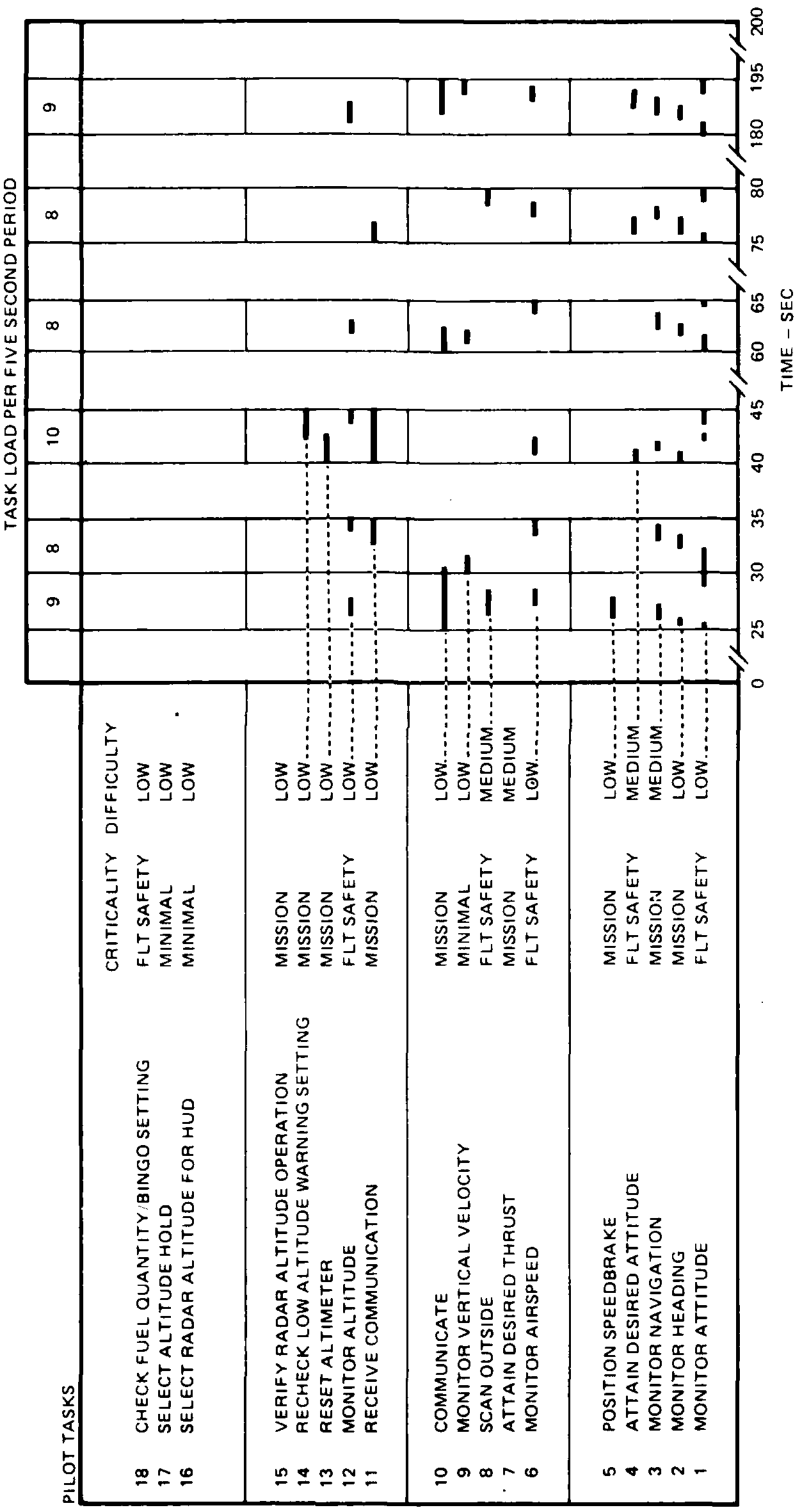


FIGURE 6.16 DYNAMIC TASK FLOWS FOR PRELANDING.

6.1.13 Landing - The tasks in this segment are performed during a fully coupled approach. A carrier-based system monitors relevant flight parameters (attitude, altitude, heading, glide slope, vertical velocity, and airspeed) and, via data link, automatically adjusts the aircraft's flight controls to compensate either for deviations from commanded levels or for changes in the orientation of the flight deck. Essentially, the pilot must process displayed flight data and must remain prepared to assume manual control if a system discrepancy is detected. He also must extend the gear, flaps and arresting hook. Just before touchdown occurs, the pilot must visually track the glide path and observe the altitude indicator (meatball) at the end of the runway. At touchdown, the pilot must apply thrust until the arresting hook catches.

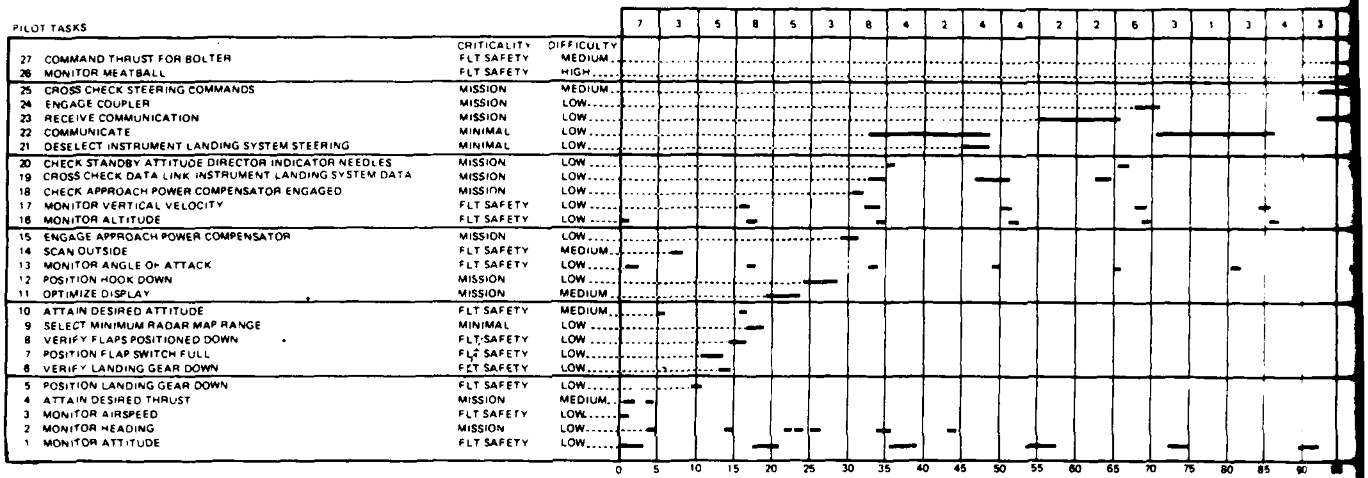
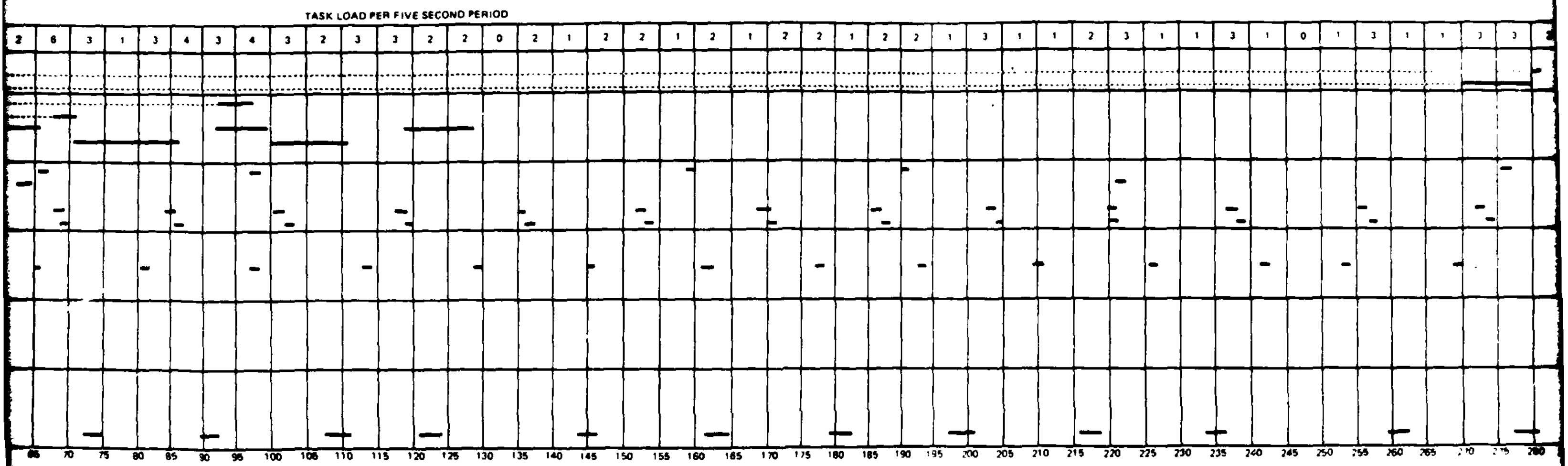


FIGURE 6.17 DYNAMIC TASK FLOWS FOR LANDING.


TASK LOAD PER FIVE SECOND PERIOD
2 6 3 1 3 4 3 4 3 2 3 3 2 2 0 2 1 2 2 1 2 1 2 2 1 2 2 1 3 1 1 2 3 1 1 3 1 0 1 3 1 1 3 3
65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280

6.2 REAL-TIME ANALYSIS AND INTERPRETATION OF BIOLOGICAL SIGNALS

Obviously, the pilot is extensively involved in monitoring displays and operating controls (flight controls and various subsystem controls). Overall mission success will be compromised when individual objectives cannot be achieved because the inherent requirements for processing information and initiating control actions exceed the capabilities of the pilot. We stated earlier that programmable, electronic displays and multipurpose keyboards offer one approach to limiting and sequencing display presentations according to the pilot's information needs at a given stage of the mission. By restricting presentations to essential flight, subsystem, and target parameters, the possibility that extraneous visual events will vie for the pilot's attention is minimized. Similarly, by integrating critical subsystem (e.g., weapons) controls directly into the stick and throttle, the speed of response is increased and the associated expenditure of physical effort is reduced.

These and other engineering advances are certainly important. However, we believe that the pilot's effectiveness could be further enhanced if (a) his current status as a processor of information and as a decision-maker were monitored, and (b) he were coupled more directly with the aircraft subsystems from a control standpoint.

We noted in the Introduction of this report that the program of biocybernetics research sponsored by DARPA has attempted to develop a communication channel for biological signals elicited during different mental activities.

It is assumed that through real-time analysis and interpretation of these signals the computer will be able to determine (within certain limits):

- when visual or auditory information has not been processed,
- when the pilot is inattentive,
- when the pilot is task-loaded to the extent that he is unable to perform additional duties,
- when the pilot lacks confidence in a decision he has made.

Subsection 6.3 outlines the courses of action which may be taken should it be necessary to unburden or assist the pilot. They include, among others:

- redistributing task responsibilities by effecting greater automation of certain housekeeping functions,
- reducing the complexity of or "decluttering" information displays, especially the HUD,
- cueing the pilot to attend to critical flight, weapons, and target data,
- displaying adaptive decision aids which present weighted recommendations for mission-related decision strategies, particularly with respect to fire control functions,
- furnishing remedial "checklists,"
- optimizing the physical characteristics (e.g., contrast, focus, etc.) of imagery and symbolic presentations.

We also will discuss "thought" commands and eye position sensing as two means of supplementing manually operated or voice actuated control systems.

In order to justify the recording (noninvasive and unobtrusive) of biological data, there are certain a priori conditions which must be satisfied. According to Donchin (in press), it first must be shown that clearly delineated and unique patterns of biological activity are, in fact, associated with specific mental (cognitive) functions; the signals cannot be ambiguous. Moreover, the signals must be interpretable in real-time as the pilot performs his tasks. Progress has been made in defining patterns of biological activity that are related to the efficacy of various cognitive functions (cf. Thatcher and John, 1977; John, 1977). Further, very significant improvements have been reported regarding the procedures used to extract (from noise) and classify these "messages" in real-time (John et al., 1978). These advances notwithstanding, a great deal more must be accomplished (in computer technology, software development, and the design of physiological monitoring equipment) before it is both feasible and practical to implement biocybernetic techniques in dynamic, operational environments. Nonetheless, we assume that the necessary breakthroughs will continue to occur.

Our intent in this subsection is to briefly review the biological signals which are most relevant for our purposes. Figure 6.18 distinguishes the two categories of signals we have considered, that is, brain electrical activity and peripheral activity. Since our principal concern is with monitoring brain function, the term "peripheral" denotes biological activity in response systems other than the central nervous system. The figure also lists two types of signals within each category, and, at a more molecular level, presents distinct informational features or components of two of the four types.

Of necessity, we have omitted many important details of the basic research findings in electrophysiology and biological signal processing which provide a foundation for the applications we have suggested. Therefore, we

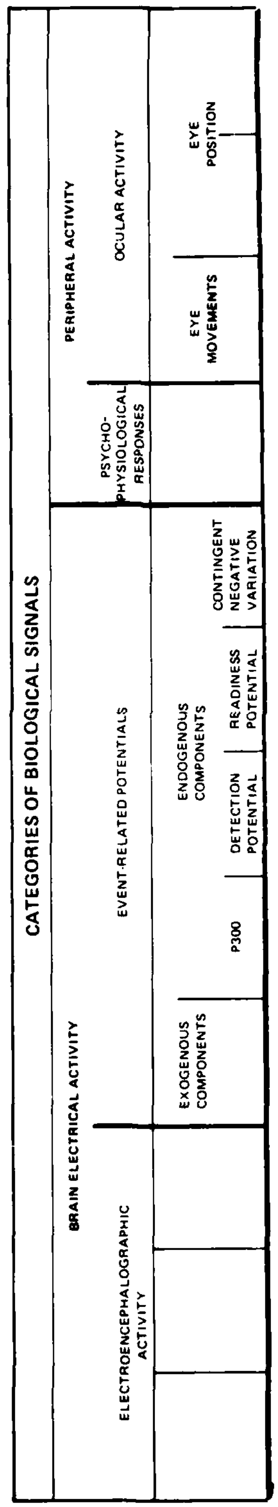


FIGURE 6.18 BIOLOGICAL SIGNALS CONSIDERED AS INPUTS FOR BIOCYBERNETIC APPLICATIONS.

encourage the reader to consult the Proceedings of the DARPA Conference on Biocybernetic Applications for Military Systems (Gomer, in press) and the many excellent textbooks and chapters (cf. Chapman, 1973; Desmedt, 1979; John and Schwartz, 1978; McCallum and Knott, 1973, 1976; Otto, 1979; Thompson and Patterson, 1974) for more complete descriptions of the progress that has been made in these areas.

6.2.1 Brain Electrical Activity - In order to evaluate brain function while a crew member performs a demanding task, we must rely upon electrophysiological techniques to observe the underlying interactions within and between populations of cortical cells. Donchin (in press), John (1977), and Thatcher and John (1977) have suggested that cognitive operations can be conceptualized in terms of coherent patterns of activity within distributed cell groups. And importantly, orderly neural behavior gives rise to rhythmic voltage fluctuations in the two types of scalp recorded electrical activity identified in Figure 6.18.

Electroencephalographic (EEG) activity consists of spontaneous or on-going voltage fluctuations (see Figure 6.19). Event-related potentials (ERPs), on the other hand, are transient voltage fluctuations which are associated with a critical inducing event (i.e., a sensory stimulus or a cognitive operation) and which are imbedded in the EEG activity. Since the EEG is generally more pronounced in amplitude, it usually obscures the waveform of the ERP. However, there are several strategies for extracting and measuring ERPs (or selected "components") in real-time (John et al., 1978).

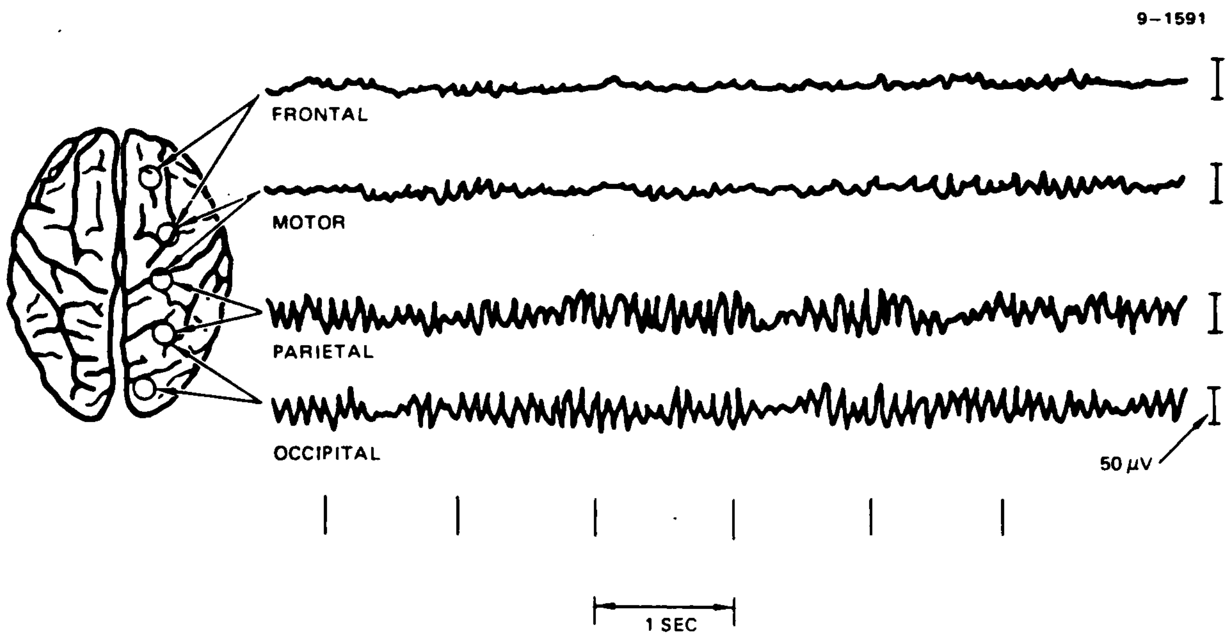


FIGURE 6.19 ELECTROENCEPHALOGRAM OF A NORMAL HUMAN ADULT. (ALPHA WAVES AT ABOUT 10 PER SECOND PREDOMINATE IN ALL REGIONS BUT ARE LARGEST POSTERIORLY. ONLY A FEW SMALLER AND FASTER BETA WAVES ARE VISIBLE IN THE ANTERIOR REGIONS. (FROM LINDSLEY, 1948))

If a discrete visual stimulus is presented to an observer who must classify it and then signify the decision he has reached with a behavioral response, the resultant ERP is composed of successive positive and negative deflections continuing for up to 750 msec post stimulus. Figure 6.20 depicts such a waveform in which the major deflections or components have been labeled by a character-number designation. The character refers to the polarity of the component (P = positive, N = negative), while the number indicates the temporal delay or latency between the eliciting event and the peak voltage of the component.

The morphology of the components occuring within 200 msec after stimulus onset is influenced markedly by the physical attributes (e.g., wavelength, intensity or contrast) of the evoking stimulus (cf. Regan, 1972). Consequently, these so-called early components are referred to as exogenous. If the input must be processed and a decision reached, the prominence of late or endogenous component activity, particularly P_{300}, is affected. The term "endogenous" signifies that these components are not affected by the sensory qualities of external events.

The location of recording electrodes must be given careful consideration when denoting the amplitude and latency of ERP components. This follows from the previously stated position that neural representations of information processing and decision-making involve the coordinated behavior of disparate cell populations. Thus, the spatiotemporal distribution of late component activity, when referenced to the International Electrode Placement System (Figure 6.21), is a most important indicator of cognitive function (cf. Adam and Collins, 1978; Courchesne, et al., 1975; Goff, et al., 1978; Thatcher, 1976).

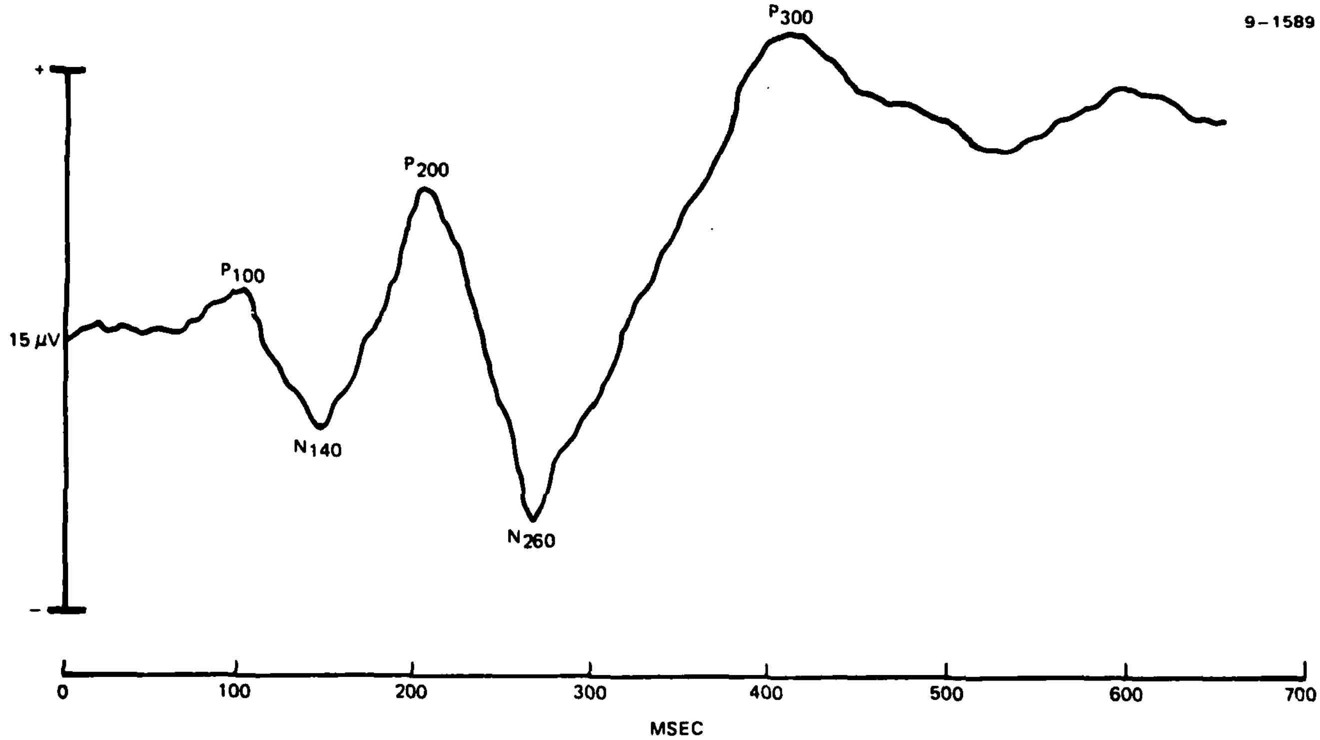


FIGURE 6.20 VERTEX EVENT-RELATED POTENTIAL ELICITED BY A MATCHING LETTER PRESENTATION DURING AN ITEM RECOGNITION TASK. (FROM GOMER ET AL., 1976)

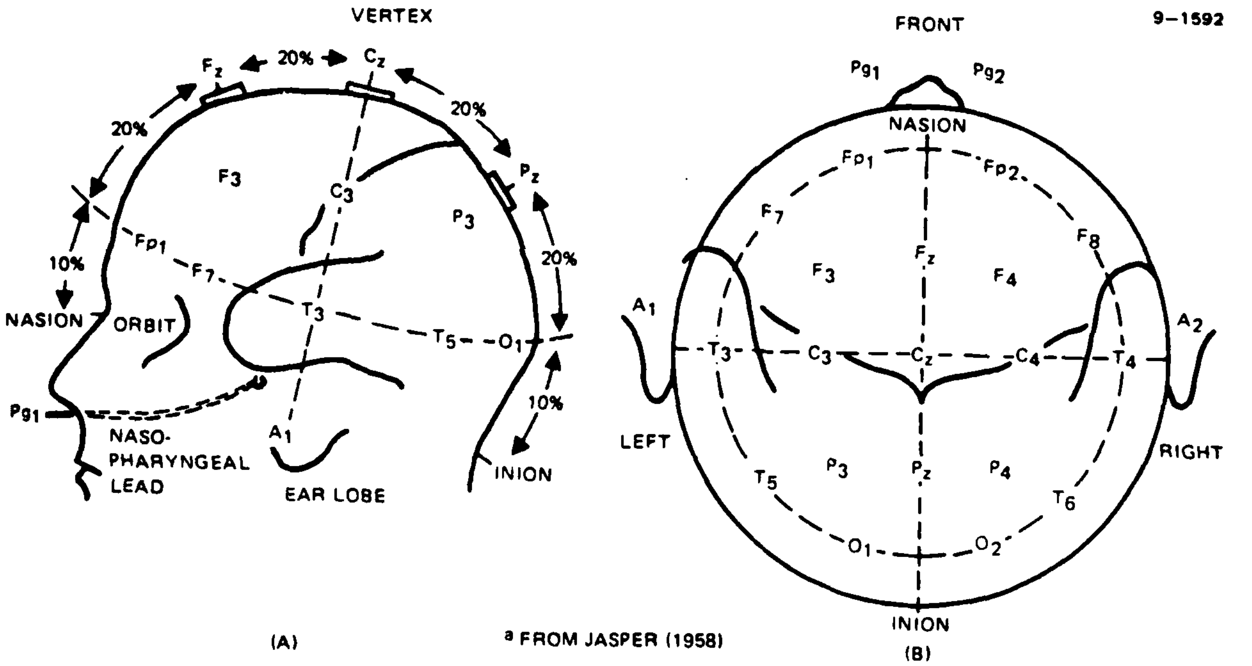


FIGURE 6.21 LATERAL AND SUPERIOR VIEWS OF INTERNATIONAL ELECTRODE PLACEMENT SYSTEM.

One may question whether it will be possible to evaluate some of the ERP components during tactical missions, since discrete visual events are rarely presented to the pilot (other than in the form of check list items). Rather, alpha numerics, symbolic characters, and sensor imagery are displayed continuously, and they change in content or value dynamically. Donchin (in press) has shown that discrete probe stimuli (in this case auditory) can be introduced artifically into those situations in which dynamic visual events predominate. By analyzing "background" responses (principally P_{300}) to these probes we can infer how well the operator is performing "foreground" tasks.

"Foreground" activities can be assessed directly however. That is, we can evaluate the EEG changes which accompany information processing and decision-making operations that are integral to the housekeeping and mission-related tasks performed by the pilot. The EEG is categorized with respect to two basic dimensions, frequency and amplitude. Usual frequency bands are:

- delta (.5 - 4Hz),
- theta (5 - 7Hz),
- alpha (8 - 12Hz),
- beta (18 - 30Hz).

Energy distributions can be measured within these and more restricted frequency bands at each recording site. In fact, energy asymmetries in homologous leads (left vs. right hemisphere) may be quite sensitive to subtle differences in cognitive function.

Figure 6.18 lists other endogenous components, two of which are of additional value for monitoring pilot status. The contingent negative variation (CNV) is a slow, negative shift in EEG baseline which develops in the interval between successive presentations of discrete stimulus events (see Figure 6.22). The time course, amplitude, and scalp distribution of this waveform provide a general index of attentiveness (Donchin, in press). Thus, the probe technique which has been used to elicit P_{300} can also be used to generate CNV responses. The detection potential (DP), in contrast, is a transient change in EEG activity which is associated with the detection of dynamic target events (McCallum, in press; Cooper et al., 1977). McCallum and his colleagues discovered this event-related slow potential during preliminary studies of extended vigilance performance. Operators viewed a static landscape which was displayed on a television monitor. At random time periods, one of several vehicular targets would appear in the scene and traverse the terrain along a prescribed route. These scientists found that a well defined, positive-going potential reliably preceded behavioral indications of target detection (see Figure 6.23). Moreover, control experiments have established that this component is not related to the initiation of motor responding per se and that it has a predominant centroparietal scalp distribution. If the scope of these investigations can be expanded to incorporate more demanding target acquisition requirements, then the pilot's participation in a very important fire control function can be monitored directly.

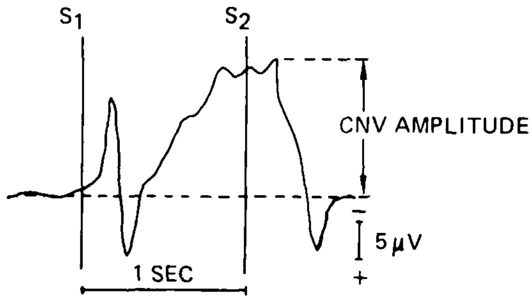


FIGURE 6.22 TYPICAL CNV WAVEFORM RECORDED FROM VERTEX ELECTRODE PLACEMENT.
(S1 AND S2 DENOTE SUCCESSIVE STIMULUS EVENTS.)

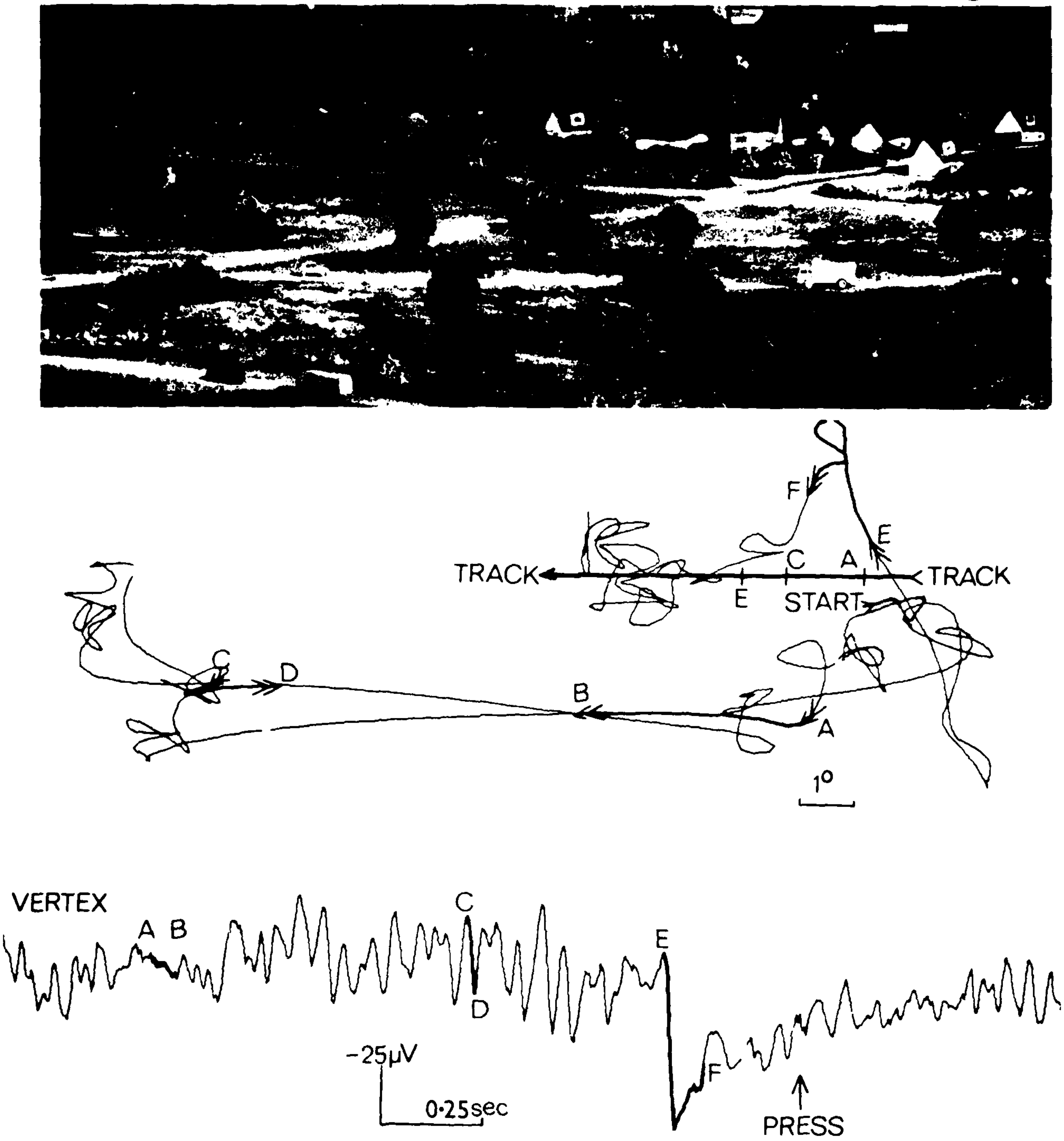


FIGURE 6.23 (TOP) THE DISPLAYED SCENE AND (BOTTOM) THE EYE-SCAN PATTERN AND VERTEX EEG OF ONE SUBJECT BEFORE AND AFTER DETECTION OF VEHICLE. (THE VEHICLE TRAVELED FROM RIGHT TO LEFT ACROSS THE MIDDLE OF THE DISPLAY. AT THE START OF THIS SECTION OF THE RECORD THE EYES WERE LOOKING AT THE CENTER OF THE DISPLAY. AT A THE EYES MOVED TO THE LEFT SIDE AND SCANNED THERE UNTIL B WHEN SACCADES TO THE UPPER CENTER C AND RIGHT DE OCCURRED, FOLLOWED BY DETAILED MOVEMENTS LEADING TO THE DETECTION POTENTIAL AT F AND TRACKING THEREAFTER. ALL SIX VEHICLES ARE SHOWN. (FROM COOPER ET AL., 1977))

We stated earlier that the recording and analysis of brain electrical activity also may permit a direct coupling of the pilot with aircraft subsystems from a control standpoint. At issue is whether it will be possible to interpret bioelectric manifestations of different thoughts as they occur, whereby the pilot can "think" to activate switches or guide control actions. Pinneo and his colleagues at Stanford Research Institute were funded by DARPA to develop this particular communication link (Pinneo et al., 1975). Their primary objective was to isolate features in the EEG data that are associated with specific thoughts. They also attempted to devise computer pattern recognition programs that would identify these features on-line. For a small vocabulary of individual commands, they concluded that consistent patterns are present in that EEG activity which is coincident with the thinking of a particular word. Further, these patterns can be recognized and classifed by a computer a statistically significant percentage of the time. It must be noted, however, that this process is not yet sufficiently reliable to be used in a practical system.

There often is a need to increase the speed with which a control action is initiated, such as in weapons release during air-to-air gun attack. Researchers have discovered a negative slow potential shift, termed the "readiness potential" (RP) (see Figure 6.24), which precedes the actual execution of a voluntary manual response by as much as several hundred milliseconds (cf., Donchin, 1979; Gaillard, 1978). It is an electrophysiological indication of the intent to commence responding. This negative wave should not be confused with the CNV that was described previously. Whereas the RP is movement-related, the CNV is influenced by variables which modulate

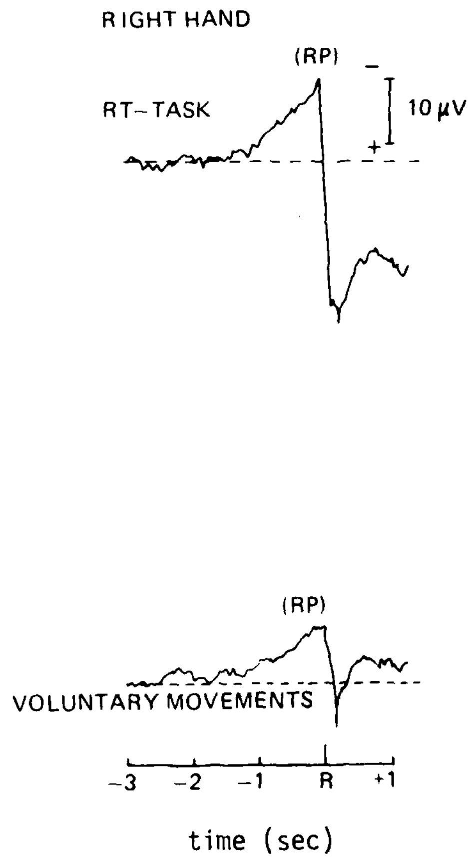


FIGURE 6.24 EXAMPLES OF VERTEX READINESS POTENTIALS ASSOCIATED WITH FINGER PRESSES DURING A REACTION TIME TASK AND DURING VOLUNTARY MOVEMENTS. **(FROM GAILLARD, 1978)**

attentiveness to task demands. Moreover, Gaillard (1978) notes that the RP is distributed more posteriorly than the CNV and that the RP is bilaterally asymmetrical while the CNV is bilaterally symmetrical.

To reiterate, there are certain conditions which must be satisfied before electrophysiological signals will be valuable in the context of military applications. With respect to monitoring pilot status, clearly delineated and unambiguous patterns of brain electrical activity must be associated with information processing, attentiveness, and decision-making. Further, optimal patterns of activity (profiles) must be defined for these cognitive functions as a pilot successfully performs housekeeping and mission-related tasks. The profiles must be continuously updated and stored in computer memory onboard the aircraft. Current electrophysiological data which are recorded during the various stages of the mission must be evaluated in comparison with the profiles for deviations from acceptable levels. In the case of control system applications, we again must identify specific features of brain electrical activity which, in this instance, correspond with distinct thoughts and with the intent to initiate a manual response. And as we stated with regard to pilot status, current electrophysiological data must be matched, in real-time, with these unique profiles.

6.2.2 Peripheral Activity - While we have deliberately focused on brain electrical activity and cognitive function, we recognize the importance of monitoring the pilot's reaction to chronic and acute stress. We are referring not only to environmental stressors, such as g forces or hypoxia, but also to psychological stressors, such as workload. If considerable bodily resources must be mobilized for extended time periods to restore the "status quo," then the pilot's proficiency in performing critical tasks will deteriorate. Therefore, we assume that sustained increases in certain types of biological activity (or perhaps in the variability of a particular measure) will reflect difficulty in coping with stress. We very briefly describe psychophysiological activity in three response systems that have been studied to assess levels of anxiety, tension, or physical effort.

Within this subsection we also review ocular activity from two perspectives. We begin by examining the dynamics of eye movements (i.e., timing, velocity, and pattern) as they relate to information extraction and processing. Then we discuss the concept of eye control.

6.2.2.1 Psychophysiological Responses - Surface recordings of electromyographic (EMG) activity are widely used to evaluate changes in tension and physical effort (cf. Goldstein, 1972; Johnson, in press). Electrodes are placed on the skin over various muscle groups, although forehead and neck leads are usually included when the effects of psychological stressors are examined. The electrical activity generated in the muscles is frequently rectified and integrated over an interval of time, the duration of which depends upon the purpose for the recording.

Shifts in cardiovascular activity also occur in response to stress and changes in physical effort. The parameters of interest to most investigators have been (a) heart rate and rhythm and (b) blood flow and pressure (Gunn et al., 1972). Heart rate (HR) has been the preferred datum when evaluating anxiety or tension, due largely to practical difficulties in acquiring the other data during simulation and operational testing. Direct measurement techniques consist of (a) recording the electrical activity generated by contraction and relaxation of cardiac muscle - the electrocardiogram (ECG), and (b) detecting the corresponding heart sounds - the phonocardiogram. Indirect techniques usually involve some form of sensing the changes in peripheral blood flow. There is a question, however, whether fluctuations in mean HR or in HR variability provide the most sensitive indication of physical status.

Similarly, both the rate and depth of respiration increase significantly when subjects are exposed to periods of stress. The most common methods for measuring these parameters incorporate impedance, strain gauge, or thermistor techniques. It must be noted that respiratory patterns are disrupted by speech, thereby limiting the value of rate and amplitude recordings during certain mission segments.

Our goal, as far as monitoring the pilot is concerned, is to identify consistent patterns of activity - not only in individual psychophysiological measures but in a group or groups of measures - that are related to distinct changes in anxiety, tension, and physical effort.

6.2.2.2 Ocular Activity - It is generally accepted that eye movements reflect the observer's distribution of attention within visual space (cf. Krebs et al., 1977). However, the timing and velocity of these movements may also reveal the effectiveness with which a pilot processes information. We suggest that ocular measures may supplement electrophysiological measures of cognitive function during display monitoring tasks. A more detailed discussion of the types of eye movements and their relation to perception and cognition is presented by Cumming (1978).

Large movements orient the eye so that the high resolution area of the retina (the fovea) is directed toward the point of interest within the visual scene. We can define three classes of large eye movements. Saccades are voluntary, abrupt changes in fixation between points located at the same viewing distance. They are characterized by accelerations and decelerations of up to 40,000 deg/sec^2 and by peak velocities of 480 to 600 deg/sec. Saccadic eye movements during visual search typically subtend 1 to 40 deg. Smooth movements, on the other hand, occur when the eyes track an object which moves vertically, obliquely, or laterally in the range of 1 to 30 deg/sec. These movements are also produced to compensate for head or body motion as the observer fixates on a stationary object. Finally, vergence movements allow the eyes to adjust to changes in viewing distance or depth.

Even when an observer carefully attempts to maintain precise fixation, small movements inevitably persist. These movements are classified as tremor, microsaccades, and drifts. According to Cumming (1978):

> "Tremor is a small, irregular lateral oscillation with frequency components up to 100 Hz and an amplitude equivalent to a few foveal cone diameters. Microsaccades are small, fast, conjugate flicks, taking some 20 msec and moving the eyes a few minutes of arc. Between microsaccades the eyes drift haphazardly at about 5 min of arc/sec, with tremor superimposed on the drifting motion. The two eyes drift independently and probably also undergo tremor independently, and so these movements have usually been attributed to unavoidable residual instability in the oculomotor system." (p. 224)

We are most concerned with the dynamics of large eye movements that occur as the pilot scans displays and the visual scene outside the crew station. Two-stage models of visual perception hold that events of interest are located initially via peripheral vision; this leads to fixation and, therefore, more detailed analysis. Many investigators believe that fixation implies attention. However, the relationships between the velocity and the amplitude (angular distance) of saccadic eye movements may provide additional insights concerning fluctuations in attentiveness or in decision strategy (Stern, 1978). Equally as important in this regard are temporal parameters, such as fixation duration (dwell time), since unusually long or short fixation pauses may reflect periods in which visual information is not being processed.

Young and Sheena (1975) have surveyed most of the procedures for measuring eye movements and eye position within the laboratory. Unfortunately, a major shortcoming of many measurement techniques is that they require varying degrees of head stabilization to achieve accurate determinations of eye position. This obviously limits their usefulness in operational crew stations. Thus, it is noteworthy that the military has developed procedures for transmitting head position (and, in an indirect manner, line-of-sight) coordinates to create a close coupling of the pilot with aircraft subsystems from a control standpoint.

Furness (in press) has reviewed several methods for deriving line-of-sight data in the cockpit to facilitate the aiming of weapons, the designation of ground targets, or the activation of control surfaces. One system which has been developed incorporates a tightly fitted helmet and a parabolic visor. A gunsight reticle is projected via an optical assembly onto the center of the visor. The reticle appears as a 10 mil ring within a 50 mil ring and is collimated. Two lead sulfide photodiodes are located on each side of the helmet, and, of course, their positions are constant with respect to the position of the reticle. In principle, as the crew member moves his head and superimposes the reticle over a target of interest, the relative positions of these two photodiodes are measured and translated into line-of-sight information. To accomplish this, an infrared scanning device is located behind the crew member on the canopy rail. It generates two parallel planes of infrared light that rotate throughout the cockpit and illuminate the two photodiodes. The signals from the photodiodes and the timing signals from the scanner are transmitted to a special-purpose digital computer. The computer determines the positions of the photodiodes in three-dimensional space and resolves the resultant vector into azimuth and elevation angles. Once relative azimuth and elevation coordinates are known, they are combined with information about aircraft boresight to specify, in an absolute sense, precisely where the crew member is aiming his head (and thus directing his gaze).

Electro-oculographic (EOG) and, to a lesser extent, oculometer techniques permit the recording of eye movements without placing restraints on allowable head movements. Merchant (in press) has recently described the development of a helmet-mounted oculometer, the design of which is based on the visor-projected reticle system used to infer line-of-sight in the cockpit. In this adaptation, the reticle generator on the side of the helmet is replaced with miniaturized versions of the oculometer sensor and the infrared illumination source. The latter projects light rays off the parabolic visor, while the former views a reflected image of the eye. Not only can the dynamics of large eye movements be studied in this manner, but eye position can be determined directly by measurement of the distance between the corneal reflection (of the light rays from the illumination source) and the pupil center.

6.3 BIOCYBERNETIC APPLICATIONS

Our premise has been that system effectiveness can be improved dramatically if the central computer is made aware of momentary shifts in operator status. In addition to monitoring transient aspects of cognitive function, we also believe it worthwhile to assess more long term or general status, as influenced by such factors as fatigue, anxiety, and physical well-being.

The previous subsection (6.2) documented that mental activities are indeed manifest in a variety of biological signals. Subsequent to computer analysis of the informational content (both phasic and tonic) of these signals, we suggested that it would be possible to unburden or assist the pilot through:

- o redistribution of task responsibilities by effecting greater automation of certain housekeeping functions,
- o reduction in the complexity of information displays, especially the HUD,
- o cues for the pilot to attend to critical flight, weapons, and target data,
- o presentation of adaptive decision aids which recommend mission-related strategies for fire control functions,
- o recall of checklist items,
- o more optimal adjustments of the physical characteristics (e.g., contrast, focus, etc.) of imagery and symbolic displays.

Moreover, we noted that (a) pattern analysis of brain electrical activity associated with either distinct "thought" commands or the intent to initiate movement and (b) eye position sensing, provided separate means of augmenting (especially in terms of speed) manually operated and voice actuated controls.

Figure 6.25 presents the biological signals listed earlier in Figure 6.18, but now links them to specific applications. With respect to electroencephalographic activity, we presume that distinctive features are sensitive to continual as well as sudden cognitive demands. Remember that "features" refer to energy distributions within restricted frequency bands and to possible asymmetries in these distributions across standard recording sites. Other features of EEG activity may emerge as trained pilots "think" particular commands, thereby creating the necessary inputs to initiate and guide control actions. As evident from the figure and the text of Subsection 6.2, exogenous and endogenous components of event-related potentials are also valuable sources of pilot information. For example, by referencing the time course, amplitude, and locus of maximal response for exogenous components of visual ERPs (since each of these attributes change as image quality and contrast are manipulated (cf. Gomer and Bish, 1978)), display settings can be adjusted automatically to achieve criterion levels of display performance. Regan (in press) recently has proposed such a "feedback loop" for a form of exogenous activity labelled steady-state.

Returning to Figure 6.25, the suggested applications for endogenous components of ERPs require no further explanation. However, we should review the information-bearing properties of the different types of peripheral activity, as well as some of the headings we have employed to depict their

CATEGORIES OF BIOLOGICAL SIGNALS				BIOCYBERNETIC APPLICATIONS
BRAIN ELECTRICAL ACTIVITY	ELECTROENCEPHALOGRAPHIC ACTIVITY			ASSESS GENERAL COGNITIVE STATUS
BRAIN ELECTRICAL ACTIVITY	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS
BRAIN ELECTRICAL ACTIVITY	ELECTROENCEPHALOGRAPHIC ACTIVITY			ACTIVATE AND/OR CONTROL SUBSYSTEMS
BRAIN ELECTRICAL ACTIVITY	EVENT RELATED POTENTIALS	EXOGENOUS COMPONENTS		ADJUST DISPLAY PARAMETERS
BRAIN ELECTRICAL ACTIVITY	EVENT RELATED POTENTIALS	ENDOGENOUS COMPONENTS	P300	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS
BRAIN ELECTRICAL ACTIVITY	EVENT RELATED POTENTIALS	ENDOGENOUS COMPONENTS	DETECTION POTENTIAL	DETERMINE WHETHER TARGET HAS BEEN DETECTED
BRAIN ELECTRICAL ACTIVITY	EVENT RELATED POTENTIALS	ENDOGENOUS COMPONENTS	READINESS POTENTIAL	FIRE WEAPONS
BRAIN ELECTRICAL ACTIVITY	EVENT RELATED POTENTIALS	ENDOGENOUS COMPONENTS	CONTINGENT NEGATIVE VARIATION	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS
PERIPHERAL ACTIVITY	PSYCHO-PHYSIOLOGICAL RESPONSES			ASSESS GENERAL PHYSICAL STATUS
PERIPHERAL ACTIVITY	OCULAR ACTIVITY	EYE MOVEMENTS		ASSESS GENERAL COGNITIVE STATUS
PERIPHERAL ACTIVITY	OCULAR ACTIVITY	EYE POSITION		ACTIVATE AND/OR CONTROL SUBSYSTEMS
PERIPHERAL ACTIVITY	OCULAR ACTIVITY	EYE POSITION		DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION

FIGURE 6.25 RELATIONSHIP BETWEEN PARTICULAR BIOLOGICAL SIGNALS AND EITHER THE DETERMINATION OF PILOT STATUS OR CONTROL FUNCTIONS.

usage. Previously, we described psychophysiological activity in three response systems that have been monitored extensively to assess tension and physical effort, particularly following the onset of stress. Therefore, we have grouped these response systems together and assumed that the principal virtue of recording from them will be to denote changes in "physical status." Again, sustained increases in the behavior of these response systems, if caused by prolonged exposure to stress, should forewarn an imminent deterioration in pilot proficiency. Finally, the dynamics of eye movements (i.e., timing, velocity, and pattern) should serve as an additional indication of the effectiveness with which a pilot extracts and processes displayed information.

In taking the process to its logical conclusion, Figures 6.26 through 6.38 present biocybernetic applications as a function of individual pilot tasks. These are tasks which occur within the various segments of the escort mission we described before in Subsection 6.1. For each of the tasks which must be performed, we have indicated whether we are seeking status information of some sort, or whether we intend to supplement conventional methods of control system activation.

We recommended earlier that biocybernetic applications be restricted to those pilot tasks which are very difficult, are critical to the success of the mission, or occur during periods of heavy workload. Whereas the original task listings in Figures 6.6 through 6.17 are quite complete, we now have eliminated less essential tasks (with respect to difficulty, criticality, or workload considerations) in constructing the biocybernetic matrices which follow. Moreover, to avoid unnecessary redundancy in the format of successive figures, we show just those tasks which have not appeared in any of the preceding matrices (starting with Figure 6.26). For example, although the pilot must determine altitude during launch as well as climb, this task is entered as a row heading only in the matrix devoted to launch.

	CATEGORIES OF BIOLOGICAL SIGN						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT-RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READINESS POTENTIAL
	BIOCYBERNETIC APPLICATIONS						
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
CHECK FLAPS UP							
CHECK LANDING GEAR UP							
RETRACT FLAPS			X				
RETRACT LANDING GEAR			X				
MONITOR RATE OF CLIMB	X	X			X		
MONITOR ALTITUDE	X	X			X		
MONITOR AIRSPEED	X	X			X		
SCAN EXTERNAL	X	X			X		
MONITOR ATTITUDE	X	X			X		
ATTAIN PROPER ATTITUDE							
MONITOR FORWARD ACCELERATION	X	X			X		

FIGURE 6.26 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING LAUNCH.

LOGICAL SIGNALS						
TIALS		PERIPHERAL ACTIVITY				
		PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY			
NOUS ENTS			EYE MOVEMENTS	EYE POSITION		
READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION					
APPLICATIONS						
FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION	
		X			X	
		X			X	
		X		X		
		X		X		
		X	X		X	
		X	X		X	
	X	X	X		X	
		X	X		X	
		X	X		X	
		X				
		X	X		X	

PILOT TASKS	CATEGORIES OF BIOLOGICAL S						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT-RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READINESS POTENTIAL
	BIOCYBERNETIC APPLICATION						
	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
GIVE WING LEVEL OFF SIGNAL							
CHECK CABIN ALTITUDE	X	X			X		
CHECK OXYGEN QUANTITY	X	X			X		
MONITOR VERTICAL VELOCITY	X	X			X		
RECEIVE COMMUNICATION			X				
COMMUNICATE			X				
UNLOCK SHOULDER HARNESS							
CLEAR VISUAL AIRSPACE WINGMAN POSITION							
ATTAIN DESIRED THRUST							
MONITOR NAVIGATION	X	X			X		
MONITOR HEADING	X	X			X		

FIGURE 6.27 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING CLIMB.

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…ES OF BIOLOGICAL SIGNALS						
…LATED POTENTIALS			PERIPHERAL ACTIVITY			
			PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
ENDOGENOUS COMPONENTS				EYE MOVEMENTS	EYE POSITION	
…ETECTION …OTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION				
…YBERNETIC APPLICATIONS						
DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
			X			
				X		X
				X		X
				X		X
					X	
					X	
			X			
		X		X		X
			X			
				X		X
				X		X

V

	CATEGORIES OF BIOLOGICA						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READIN POTENTI
	BIOCYBERNETIC APPLICAT						
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
RETURN RADAR TO SEARCH MODE			X				
VISUALLY MONITOR STRIKE FORCE							
CHECK RADAR ELEVATION COVERAGE	X	X			X		
CHECK RADAR AZIMUTH SCAN	X	X			X		
CHECK RADAR RANGE SCALE	X	X			X		
MONITOR AUTOMATIC DIRECTION FINDER BEARING	X	X			X		
SELECT AUTOMATIC DIRECTION FINDER			X		X		

FIGURE 6.28 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING RENDEZVOUS.

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ORIES OF BIOLOGICAL SIGNALS						
-RELATED POTENTIALS			PERIPHERAL ACTIVITY			
			PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
ENDOGENOUS COMPONENTS						
DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
IOCYBERNETIC APPLICATIONS						
DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
					X	
			X	X		X
		X				X
					X	

V

PILOT TASKS	CATEGORIES OF BIOLOGICAL SIGNALS: BRAIN ELECTRICAL ACTIVITY — ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS — EXOGENOUS COMPONENTS	EVENT RELATED POTENTIALS — ENDOGENOUS COMPONENTS: P300	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION	PSYCHOPHYSIOLOGICAL RESPONSES
BIOCYBERNETIC APPLICATIONS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS
MONITOR RADAR DISPLAY	X	X			X				
CHECK FUEL STATUS	X	X			X				
MONITOR ENGINE INSTRUMENTS	X	X			X				
MAINTAIN VISUAL SURVEILLANCE								X	X
SET RADAR STORAGE (TARGET DISPLAY) TIME			X						
CHECK AIR TO AIR ARMAMENT STATUS	X	X			X				
VERIFY SPARROW MISSILE SELECTED	X								
SELECT AIR TO AIR MODE			X						
VERIFY MODE SELECT (PROGRAM)	X								
CHECK JAMMER DISPENSE COUNTER	X	X			X				
CHECK FLARE DISPENSE COUNTER	X	X			X				
CHECK CHAFF DISPENSE COUNTER	X	X			X				
VERIFY AUTOMATIC CHAFF DISPENSE ENABLE	X							X	
VERIFY CHAFF DISPENSE ENABLE	X								
ADJUST BRIGHTNESS OF THREAT DISPLAY	X		X	X					
SET RADIO VOLUMES			X	X					
VERIFY ELECTRONIC COUNTERMEASURE SELECTED	X	X							
VERIFY SAM RECEIVER ON									
TURN RADAR ALTIMETER OFF			X						
TURN TACTICAL AIR NAVIGATION TO RECEIVE			X						
TURN IDENTIFY-FRIEND OR FOE TO STANDBY			X						
VERIFY CROSSING OF THE FORWARD EDGE OF BATTLE AREA	X	X							X

FIGURE 6.29 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING INGRESS.

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GNALS				
	PERIPHERAL ACTIVITY			
	PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
		X		
		X		X
		X		X
X	X	X		X
			X	
				X
				X
			X	
				X
		X		
		X		
		X		
X				X
				X
			X	
				X
				X
			X	
			X	
			X	
	X	X		X

	CATEGORIES OF BIOLOGICAL SIGNALS								
	BRAIN ELECTRICAL ACTIVITY								PSYCH PHYSIOLO RESPON
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS					
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS				
					P300	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION	
	BIOCYBERNETIC APPLICATIONS								
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS
CHECK NAVIGATION DATA	X	X			X				X
SET MASTER ARM TO SAFE			X						
OBSERVE FLASHING BREAKAWAY CUE					X				
OBSERVE MISSILE TIME OF FLIGHT	X	X			X				
VERIFY MISSILE LAUNCH									
DEPRESS TRIGGER			X				X		
OBSERVE IN RANGE CUE					X			X	
OBSERVE LAUNCH LIMITS STEERING, ALLOWABLE STEERING ERROR	X	X			X				
FLY STEERING DOT COMMANDS									X
JETTISON FUEL TANKS			X						
CHECK SPARROW MISSILE STATUS	X	X			X				
SCAN EARLY WARNING DISPLAY TARGET STROBE BEARING	X	X			X				
NOTE AIR INTERCEPT WARNING LIGHT									X
OBSERVE RADAR TRACKING TARGET ASSESS DATA	X	X			X	X			
VERIFY LOCK ON		X			X				
DEPRESS THROTTLE DESIGNATOR CONTROL TO LOCK ON			X						
POSITION ACQUISITION SYMBOL			X						
RECEIVE ACKNOWLEDGMENT								X	
SET MASTER ARM TO ARM			X						
OBSERVE AZIMUTH SCAN	X	X			X				
OBSERVE ALTITUDE COVERAGE	X	X			X				
SET ANTENNA ELEVATION			X						
SELECT VELOCITY SEARCH MODE			X						

FIGURE 6.30 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING MEDIUM RANGE INTERCEPT.

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L SIGNALS					
		PERIPHERAL ACTIVITY			
		PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
ESS IAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
TIONS					
	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
		X			X
				X	
					X
			X		X
	X		X		X
			X		X
		X			
				X	
			X		X
			X		X
		X	X		
			X		X
				X	
				X	
	X				
				X	
				X	

PILOT TASKS	CATEGORIES OF BIOLOGICAL						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READINE[...] POTENTI[...]
	BIOCYBERNETIC APPLICATI[...]						
	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
PERFORM EVASIVE MANEUVERS	X	X	X		X	X	
TRACK SAM VISUALLY							
ACTIVATE ELECTRONIC COUNTERMEASURES CHAFF			X				
DETECT SAM LAUNCH ON THREAT LIGHT						X	
MONITOR THREAT DISPLAY (SAM SITE AZIMUTH)	X	X			X		
DETECT ENEMY RADAR LOCK ON						X	
CHECK ELECTRONIC COUNTERMEASURES MODE	X	X					
CHECK DEFENSE ELECTRONIC COUNTERMEASURES	X	X					

FIGURE 6.31 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING SURFACE-TO-AIR MISSILE AVOIDANCE.

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EGORIES OF BIOLOGICAL SIGNALS							
				PERIPHERAL ACTIVITY			
NT-RELATED POTENTIALS				PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
	ENDOGENOUS COMPONENTS				EYE MOVEMENTS	EYE POSITION	
	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION				
BIOCYBERNETIC APPLICATIONS							
	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
	X		X	X	X	X	X
			X	X	X		X
						X	
	X						X
							X
	X						
				X	X		X
				X	X		X

V

PILOT TASKS	CATEGORIES OF BIOLOGICAL SIGNALS: BRAIN ELECTRICAL ACTIVITY – ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS – EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS – P300	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION	PSYCHOPHYSIOLOGICAL RESPONSES
BIOCYBERNETIC APPLICATIONS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS
DETECT STRIKE FORCE RADAR						X			
SELECT NAVIGATION MODE	X	X	X		X				
DETERMINE NEW HEADING TO STRIKE FORCE	X	X							
CHECK ANGLE OF ATTACK									
OBSERVE RETICLE OVER TARGET	X	X			X			X	
OPTIMIZE RETICLE DYNAMICS			X	X					
CHECK ROUNDS REMAINING	X	X							
OBSERVE GUN SYMBOLOGY	X	X			X				
SELECT GUN MODE	X	X	X						
VISUALLY ASSESS MISSILE SUCCESS									X
VISUALLY MONITOR MISSILE FLIGHT									X
VISUALLY VERIFY MISSILE LAUNCH									X
OBSERVE IN RANGE CUE SHOOT LIGHT	X	X				X		X	X
HEAR MISSILE TONE CHIRP						X			
MAINTAIN STEER DOT WITHIN ALLOWABLE STEERING ERROR	X	X			X				X
DEPRESS UNCAGE SWITCH			X						
HEAR MISSILE TONE ABOVE THRESHOLD					X	X			
OBSERVE TARGET DETECTION BOX SIDEWINDER CIRCLE ALIGNMENT	X	X							X
PUSH RUDDER PEDALS			X						
EXTEND RETRACT SPEEDBRAKE			X						
OBSERVE TARGET DETECTION BOX OVER TARGET									X
SELECT VISUAL ACQUISITION MODE HACQ VACQ BORESIGHT			X						
OBSERVE SIDEWINDER SYMBOLOGY STATUS	X	X			X				
SELECT SIDEWINDER MODE			X						
TRACK TARGET VISUALLY									X
CHECK IR COOL NORM	X	X			X				
CHECK FUEL STATUS BINGO SETTING	X	X			X				

FIGURE 6.32 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING AIR COMBAT MANEUVERING.

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...AL SIGNALS		PERIPHERAL ACTIVITY			
		PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
...NESS ...TIAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
...ATIONS					
	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
				x	
			x		
					x
	x				x
					x
					x
				x	
		x	x		x
		x	x		x
		x			x
	x	x	x		x
		x			
				x	
		x	x		x
				x	
				x	
		x	x		x
				x	
				x	
		x	x		x
					x
					x

	CATEGORIES OF BIOLOGICAL SIGNA						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READINESS POTENTIAL
	BIOCYBERNETIC APPLICATIONS						
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
OBSERVE FLASHING SYMBOLOGY					X		
DEPRESS PICKLE BUTTON			X				X
SELECT HUD SYMBOLOGY			X				
TRACK TARGET IN HUD FIELD OF VIEW	X	X		X			
OBSERVE DELIVERY MODE SYMBOL	X	X					
MODIFY ARM PROGRAM AS REQUIRED			X				
CHECK DELIVERY MODE	X	X					
CHECK ARMAMENT PROGRAM	X	X					
SELECT AIR GROUND MASTER MODE			X				

FIGURE 6.33 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING AIR-TO-GROUND STRIKE.

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OF BIOLOGICAL SIGNALS						
D POTENTIALS			PERIPHERAL ACTIVITY			
			PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
ENDOGENOUS COMPONENTS				EYE MOVEMENTS	EYE POSITION	
CTION NTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION				
RNETIC APPLICATIONS						
HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
			X	X		
	X					X
						X
		X	X	X		X
						X
					X	
						X
						X
			X	X	X	

2

	CATEGORIES OF BIOLOGICA[L]						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READ[INESS] POTEN[TIAL]
	BIOCYBERNETIC APPLICA[TIONS]						
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
DISPENSE CHAFF			X				
PERFORM SAM EVASIVE MANEUVER	X	X	X		X	X	
VISUALLY TRACK SA-6							
SELECT PROGRAM OR SINGLE DISPENSE			X				
SELECT CHAFF DISPENSE			X				
CHECK THREAT DISPLAY BRIGHTNESS				X			
VERIFY ELECTRONIC COUNTERMEASURES SELECTED	X	X					
VERIFY ELECTRONIC COUNTERMEASURES ON	X	X					

FIGURE 6.34 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING EGRESS.

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GORIES OF BIOLOGICAL SIGNALS							
NT-RELATED POTENTIALS				PERIPHERAL ACTIVITY			
	ENDOGENOUS COMPONENTS			PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
BIOCYBERNETIC APPLICATIONS							
	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
						X	
	X		X	X	X	X	X
				X	X		X
						X	
						X	
							X
				X	X		X

KS

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1

	CATEGORIES OF BIOLOGICAL SIGNALS								
	BRAIN ELECTRICAL ACTIVITY								PSYCHO-PHYSIOLOGICAL RESPONSE
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT RELATED POTENTIALS					
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS				
					P300	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION	
	BIOCYBERNETIC APPLICATIONS								
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS
CONFIRM POSITION OF ECHELON	X	X							
CHECK INDICATOR FOR CORRECT AMOUNT									
NOTE TANKER STANDBY GREEN OFF					X	X			
CHECK TANKER STANDBY GREEN ON					X	X			
OBSERVE TRANSFER LIGHT OFF					X	X			
CHECK TRANSFER LIGHT ON					X	X		X	
CHECK TANKER READY LIGHT ON					X				
CHECK DROGUE EXTENDED	X	X			X	X			
SET REFUELING SWITCHES			X						
CHECK PROBE FULLY EXTENDED	X	X			X	X			
POSITION PROBE TO EXTEND	X	X	X						
SET EXTERNAL LIGHTS TO STANDBY BRIGHT			X						
DESELECT AUTOMATIC DIRECTION FINDER			X						
DEACTIVATE AUTOMATIC FLIGHT CONTROL SYSTEM			X						
FLY FORMATION THRUST									X
FLY FORMATION ATTITUDE									X
CHANGE TO REFUEL FREQUENCY			X						
CHECK MASTER ARM SAFE									
VERIFY ALTITUDE SETTING									
VERIFY LOCK ON								X	
COMMAND LOCK ON			X						
DESIGNATE TARGET FOR LOCK ON			X			X			
CHECK AERIAL REFUELING CONTROL POINT COORDINATES	X	X			X				
SELECT SECTION SCAN			X						
SELECT BAR SCAN			X						
SELECT RADAR RANGE	X	X	X						
ENABLE WAYPOINT			X						
SELECT RENDEZVOUS FREQUENCY			X		X				
SET IN AERIAL REFUELING CONTROL POINT COORDINATES	X	X	X						
SELECT TARGET CLEARANCE ALTITUDE CHANNEL AIR TO AIR MODE			X						X

FIGURE 6.35 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING IN-FLIGHT REFUELING.

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...OGICAL SIGNALS					
...ALS		PERIPHERAL ACTIVITY			
		PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
...OUS ...NTS			EYE MOVEMENTS	EYE POSITION	
READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION				
...PPLICATIONS					
...FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
					X
					X
			X		X
			X		X
			X		
	X		X		
			X		X
					X
				X	
					X
				X	X
					X
					X
					X
		X	X		X
		X	X		X
				X	
					X
					X
	X				X
				X	
				X	
				X	
				X	
				X	
				X	
				X	
				X	
		X	X	X	

...KS

2

	CATEGORIES OF BIOLO						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT-RELATED POTENTIAL			
				EXOGENOUS COMPONENTS	ENDOGENO COMPONENT		
					P300	DETECTION POTENTIAL	
	BIOCYBERNETIC APP						
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	
CHECK MULTIMODE DISPLAY FOR AUTOMATIC CARRIER LANDING STATUS	X	X			X		
VERIFY DATA LINK FREQUENCY							
SELECT COURSE	X	X	X		X		
SELECT INSTRUMENT LANDING SYSTEM ON STANDBY ATTITUDE DIRECTOR INDICATOR			X				
VERIFY INSTRUMENT LANDING SYSTEM CHANNEL	X	X			X		
VERIFY BEACON CHANNEL	X	X			X		
SELECT AUTOMATIC CARRIER LANDING			X				
VERIFY IDENTIFY FRIEND OR FOE CODE	X	X					
ENTER IDENTIFY FRIEND OR FOE DIGITS			X				
SELECT IDENTIFY FRIEND OR FOE	X	X					
POSITION SPEEDBRAKES			X				
ADJUST CABIN AIR AS REQUIRED			X				
SELECT RADAR OPERATE	X	X	X				
SELECT WAYPOINT	X	X	X				
ACTIVATE RADAR ALTITUDE			X				
DEPRESS ENTER			X				
SELECT TACTICAL AIR NAVIGATION	X	X	X		X		

FIGURE 6.36 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING MARSHAL.

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TEGORIES OF BIOLOGICAL SIGNALS

VENT-RELATED POTENTIALS				PERIPHERAL ACTIVITY			
	ENDOGENOUS COMPONENTS			PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
BIOCYBERNETIC APPLICATIONS							
	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
				X	X		X
							X
						X	
						X	
							X
							X
						X	
			X		X		X
						X	
						X	
						X	
						X	
						X	
						X	
						X	
				X	X	X	

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	CATEGORIES OF BIOLOGICAL SIGN						
	BRAIN ELECTRICAL ACTIVITY						
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT-RELATED POTENTIALS			
				EXOGENOUS COMPONENTS	ENDOGENOUS COMPONENTS		
					P300	DETECTION POTENTIAL	READINESS POTENTIAL
	BIOCYBERNETIC APPLICATIONS						
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS
VERIFY RADAR ALTITUDE OPERATION	X	X			X		
RECHECK LOW ALTITUDE WARNING SETTING	X	X			X		
RESET ALTIMETER	X	X	X				

FIGURE 6.37 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING PRELANDING.

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ES OF BIOLOGICAL SIGNALS							
ATED POTENTIALS			PERIPHERAL ACTIVITY				
ENDOGENOUS COMPONENTS			PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY			
TECTION TENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION		
YBERNETIC APPLICATIONS							
DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION	
						X	
						X	
			X	X	X		

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	CATEGORIES O					
	BRAIN ELECTRICAL ACTIVITY					
	ELECTROENCEPHALOGRAPHIC ACTIVITY			EVENT-RELATED		
				EXOGENOUS COMPONENTS	P300	DETECTI POTENTI
	BIOCYBERN					
PILOT TASKS	ASSESS GENERAL COGNITIVE STATUS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	ACTIVATE AND OR CONTROL SUBSYSTEMS	ADJUST DISPLAY PARAMETERS	EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED
COMMAND THRUST FOR BOLTER			X			
MONITOR MEATBALL						
CROSS CHECK STEERING COMMANDS	X	X			X	
ENGAGE COUPLER			X			
CHECK STANDBY ATTITUDE DIRECTOR INDICATOR NEEDLES	X	X			X	
CROSS CHECK DATALINK/INSTRUMENT LANDING SYSTEM DATA	X	X			X	
CHECK APPROACH POWER COMPENSATOR ENGAGED	X	X			X	
ENGAGE APPROACH POWER COMPENSATOR			X			
POSITION HOOK DOWN			X			
OPTIMIZE DISPLAY				X		
SELECT MINIMUM RADAR MAP RANGE	X	X	X			
VERIFY FLAPS POSITONED DOWN	X	X				
POSITION FLAP SWITCH FULL			X			
VERIFY LANDING GEAR DOWN	X	X				
POSITION LANDING GEAR DOWN			X			

FIGURE 6.38 BIOCYBERNETIC APPLICATIONS AS A FUNCTION OF PILOT TASKS DURING LANDING.

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CATEGORIES OF BIOLOGICAL SIGNALS							
EVENT RELATED POTENTIALS				PERIPHERAL ACTIVITY			
				PSYCHO-PHYSIOLOGICAL RESPONSES	OCULAR ACTIVITY		
ENDOGENOUS COMPONENTS							
P300	DETECTION POTENTIAL	READINESS POTENTIAL	CONTINGENT NEGATIVE VARIATION		EYE MOVEMENTS	EYE POSITION	
BIOCYBERNETIC APPLICATIONS							
EVALUATE MOMENTARY ABILITY TO PROCESS INFORMATION AND MAKE APPROPRIATE DECISIONS	DETERMINE WHETHER TARGET HAS BEEN DETECTED	FIRE WEAPONS	EVALUATE MOMENTARY FLUCTUATIONS IN ATTENTIVENESS	ASSESS GENERAL PHYSICAL STATUS	ASSESS GENERAL COGNITIVE STATUS	ACTIVATE AND/OR CONTROL SUBSYSTEMS	DETERMINE WHETHER GAZE HAS BEEN DIRECTED TO APPROPRIATE LOCATION
				X		X	
				X			X
X				X	X		
				X		X	
X				X	X		X
X			X	X	X		X
X				X	X		X
				X		X	
				X		X	
				X			
				X	X	X	
			X	X	X		X
				X		X	
				X	X		X
				X		X	

7.0 CONCLUSIONS AND RECOMMENDATIONS

In proposing to add a communication channel from the pilot to the central computer, we have shown that electrophysiological measures are relatable to pilot status and, ultimately, to performance. Further, we have made the distinction between the long term changes in cognitive function that occur across the mission, and the more transient aspects of information processing and decision-making which are associated with specific pilot tasks. As McCallum (in press) notes, however, it has not been determined whether a single physiological measure can serve as a reliable index of operator status, or, rather, if several response systems must be monitored to reveal operator states which may threaten performance. This issue of single vs. multiple inputs also must be resolved in deciding upon the most effective means of augmenting conventional methods of control activation.

We did not rank the various mission segments when suggesting biocybernetic applications in the last subsection. A ranking could have been made dependent upon the relative importance of each mission segment, either with respect to the overall mission objectives or with regard to survivability. Clearly, if we were forced to be selective (perhaps due to cost/benefit considerations) in applying biocybernetic techniques, we would choose those mission segments or requirements for which the pilot is especially vulnerable and both the accuracy and speed of performance are critical. In reviewing the in-flight mission requirements presented in Section 4, we find that the following, which occur during air-to-air or air-to-ground engagements, place the greatest demands on the pilot:

- o penetration
- o threat warning

- o detection
- o location
- o identification
- o decision
- o execution
- o assessment

The principal tasks which must be accomplished within these mission requirements may collectively be termed fire control functions. That is, we are concerned with the pilot's ability to establish correct range, azimuth, elevation, and/or FOV coordinates for the sensors used during the target acquisition process. Moreover, we are concerned with his ability to interpret multisensor imagery and to select laser/EO designators and, if necessary, countermeasures. Then, if we assume that appropriate range and/or velocity considerations have been taken into account in choosing the weapon, that arming has been accomplished prior to the engagement, and that the actual time of release is computed automatically, we are concerned with the pilot's ability to maneuver the aircraft so that the target is positioned within the missile launch or gun envelope. Superimposed upon these responsibilities is a general accountability for flight control, navigation, communications, subsystems monitoring, and, especially, threat detection/evasion.

As the pilot participates in fire control functions not managed directly by the computer, our principal information needs are related to momentary fluctuations in the pilot's capacity to process information and reach decisions. If real-time measures of pilot status are available, computer graphic techniques can be called upon to create pictorial and symbolic displays with sufficient detail to lead the pilot through changing tactical situations and weapons procedures. These decision aids will enable the pilot to adopt strategies for action which are in accordance with the current posture of the mission.

Most of the electrophysiological studies we cited earlier took place in university laboratories, and the task demands imposed upon the subjects were somewhat constrained from an operational point of view. It is apparent that the progression of a program which considers electrophysiological signals as input to adaptive military systems will require that investigations be extended to appropriate part-task and full-mission simulations. Thus, we presently are conducting part-task flight simulations in which we have challenged the pilot's ability to make multiple decisions within short periods of time. Our intent in these investigations is to further define the features of brain electrical activity and eye behavior which, when analyzed on-line during the simulation, may forewarm imminent deteriorations in pilot performance.

Finally, we should note that biocybernetic applications are, in fact, being addressed by the military laboratories (cf. O'Donnell and Hartman, in press). Reising (in press), of the Air Force Flight Dynamics Laboratory, has predicted that techniques which yield pilot status information will be an essential component of adaptive crew stations in the future. Moreover, pattern analysis of "thought"-related EEG activity for control purposes has been discussed recently by scientists from the Air Force Aerospace Medical Research Laboratory (Aviation Week and Space Technology, Vol. 110, Number 5, 1979, pp. 239-243). It would seem that the high-risk program sponsored by DARPA over the past several years may significantl: influence R&D activities within the military and aerospace industries.

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